EXPERIMENTS IN PHYSICS

EXPERIMENTS IN PHYSICS

FOR STUDENTS OF SCIENCE AND ENGINEERING

BY

ERNEST BLAKER

ASSISTANT PROFESSOR OF PHYSICS IN CORNELL UNIVERSITY

Printed expressly for students in a first year laboratory course in general physics in Cornell University.

ITHACA, N. Y.
STEPHENS PUBLISHING COMPANY.
1905.

Leslie Lyle Campbell

PREFACE.

The collection of experiments printed in this book has been arranged and modified to meet the demands of a particular elementary course in laboratory physics at Cornell University and is therefore not published.

The laboratory course for which this manual is intended as a hand-book supplements a lecture course and also a recitation course in general physics in which the text used serves as a general reference for the theory on which the experiments are based.

For the most part the experiments, selected from many sources, have been used in the work for several years. The directions being type written or mimeographed have been changed from time to time as was deemed necessary. Graphical as well as numerical methods are insisted on. Occasional notes and explanations are given, and forms are many times suggested for tabulating data and results. In some cases no suggestions for tabulation are given in order that the student may show what he can do for himself.

At the end of the book will be found a list of useful tables in Watson's Physics. There are also tables of physical constants, useful numbers, logarithms and natural trigonometrical functions.

I take this occasion to thank the many who have aided in one way or another to make it possible to print the book and especially to give thanks to Professor H. J. Rogers of Leland Stanford University who first developed the course, and to Mr. Willard J. Fisher, instructor in Physics at Cornell University, for many valuable suggestions and aid in getting out the work.

ERNEST BLAKER.

TABLE OF CONTENTS.

PART I—MECHANICS.

PART II—HEAT.

PART III--SOUND.

PART IV--LIGHT.

PART V—ELECTRICITY AND MAGNETISM.

PART VI—TABLES.

Errata.

Page 26, in title, read constant for constany.

Page 28, in table read $K=\frac{186\cdot 9}{21\cdot 69}$ for $K=\frac{186\cdot 0}{21\cdot 69}$.

Page 29, line 3, read $-\omega^2 x$ for $\omega^2 x$.

Page 29, line 6, read $m\ddot{x}$ for mx.

Page 30, lines 14 and 15, read Hooke's for Hook's.

Page 37, in figure 8, F and f should be interchanged.

Page 39, line 4 from bottom, read f_2 for f.

Page 41, line 6 from bottom, read f_1 for w.

Page 47, line 2, read $F_2 l$ for $F l$.

line 6, read radians for radious.

Page 58, line 11 from bottom, read base radius for radius.

Page 59, bottom line, read 6 for 24.

Page 63, line 2 read 25 for 26.

Page 67, line 1 read L^3 for B^3.

Pages 86 and 87, throughout read N for n.

Page 87, title, read IN for IF.

Page 100, line 9 from bottom, read μ is for is μ.

Page 112, formula (4) should read $v=+\frac{L}{2}\pm\frac{1}{2}\sqrt{(L^2-4fL)}$

Page 116, line 9 from bottom, read readjust for read just.

Page 125, line 1, read magnet for magnate.

Revised References for the Fourth Edition of Watson's Physics.

Page 34 omit § 75.

In experiments 20 to 27 inclusive decrease by *one* the numbers of the paragraphs cited.

In experiment 50 increase by *two* the numbers of the paragraphs cited.

In experiments 51 to 103 inclusive increase by three all numbers of paragraphs cited which refer to Watson's Physics.

In part VI, table I, the page references to tables in the fourth edition of Watson's Physics should read, 10, 11, 20, 21, 89, 109, 144, 167, 169, 187, 195, 197, 208, 225, 239, 240, 250, 272, 285, 398, 415, 514, 532, 680.

INTRODUCTION.

In the following paragraphs will be found a few rules of the laboratory and some general hints as to methods of doing the laboratory work and writing up reports.

It is expected that every student will be prompt and regular in attendance. Excused absences may be made up at periods to be arranged for by the student with his instructor. The grade of each student will depend on the amount of exeprimental work successfully performed, the neatness, arrangement and completeness of data and reports and the final examinations.

The notes in the manual should be carefully read and the references cited should be studied before coming to the laboratory. It is best to be familiar with the notes and references on two or three experiments in advance as it frequently is not convenient to assign experiments in regular order. The experiments are arranged in groups. In general each student is to perform one experiment from each group. Each student is held responsible for all the apparatus he is using whether working alone or with a partner. Apparatus taken from the apparatus room will be charged to the student when drawn out and he will be credited with it when returned.

In performing experiments and making computations students working together should share alike, but all other work should be strictly individual.

OBSERVATIONS.—All original observations are to be recorded in the note book at the time of performing the experimental work, in such a manner as to present a neat appearance and to follow some logical order which may be easily followed by one having a knowledge of the requirements of the experiment. In many cases some such order will be suggested in the manual.

Errors of judgment as well as mistakes are always to be carefully guarded against, and previous observations and preconceived notions must not be allowed to bias one's observations. All observations are to be made with care and are to be recorded exactly as made, even when apparently wrong. When an observation is known to be wrong it may be omitted from the computations, reasons being given.

In measuring quantities which require scale readings, it generally happens that the readings to be taken will not fall on marked divisions. It is then necessary to estimate tenths of divisions, as in estimating tenths of degrees on a thermometer graduated in degrees only. The smaller the quantity observed the greater should be the care used in making the observations. The percentage error, that is, the ratio of the absolute error to the true value of the quantity measured, increases with a decrease of the quantity measured. The accuracy of the result depends on the percentage error. As an example suppose the volume of a long slender wire is to be measured. $V = l \pi r^2$. Since r, the radius, is supposed to be small compared with l, the length of the wire, the accuracy of the result depends more on an accurate measurement of r than of l.

In general one observation of a quantity is not sufficient.

1. **COMPUTATIONS.**—Simple numerical errors are of frequent occurrence and are to be carefully guarded against. Reports containing numerical errors will not be accepted. In making computations the physics of the experiment must not be lost sight of.

The slide rule is a very useful instrument for making computations such as multiplication, division, finding powers and extracting square roots, and in most cases the results are sufficiently accurate. It has the great advantage of being a great time saver. A little careful practice will soon make it possible to carry out computations with an error of less than one per cent.

Do not carry out computations to a degree unwarranted by

the accuracy of the observations. Observational errors will usually be not less than 1% and may sometimes be as great as 5% therefore it is generally not necessary to carry computations beyond the third significant figure irrespective of the position of the decimal point. Zeros must often be used as significant figures. If a weighing be made that is equal to seventeen grams with an error in tenths of milligrams it should be indicated thus: 17.000. If the weighing is correct to hundredths of grams it should be written 17.0. If a certain computation has twelve places to the left of the decimal point only three of which are accurate the result is not to be expressed as 217384950607 nor as 217,000,000,000 but as $217\text{x}10^9$ or $21.7\text{x}10^{10}$. It is often convenient to express such qualities as .000328 in the following form, $328\text{x}10^{-6}$. This method of writing results has the merit of brevity but its greatest utility is in indicating the accuracy of the work.

Carry divisions out as far as the corresponding multiplications would be carried. Several independent determinations of the same quantity will usually differ. If this difference occurs beyond the third significant figure computations should be carried out until the difference does appear. The percentage deviation of a few of the independent determinations from the mean should be found.

REPORTS.—Always begin a report at the top of a left hand page so that at least two pages of the report may face each other. Head the report with a title and the date. Do not crowd the data or other matter. Try to give the report as neat an appearance as possible.

Give definitions of physical terms used for the first time, and a full statement of new laws as they come up. Include all equations used and give indicated numercial substitutions in them. Put in the reports explanatory diagrams; and always give complete diagrams of electrical connections exactly as made. Whenever possible graphical representations of results

should be made. (Watson §§ 33–36). Finally, state clearly what facts have been verified, and give a clear formal conclusion to the report. Index all reports on the first page of the note book.

CURVE PLOTTING.—The following brief rules and accompanying diagram will illustrate the process.

1. Never use less than half of a page. In many cases a full page is advisable.

2. Draw a horizontal base line and erect near the left hand edge of the paper a vertical line intersecting it. These lines, the axes, serve for guides. Choose such scales for plotting the variables that the largest values of them will be near the right hand and upper edges of the plot using scales that may easily be read, such as one division for one, two, five or ten units or like sub-multiple units. More than one curve may be plotted on the same sheet.

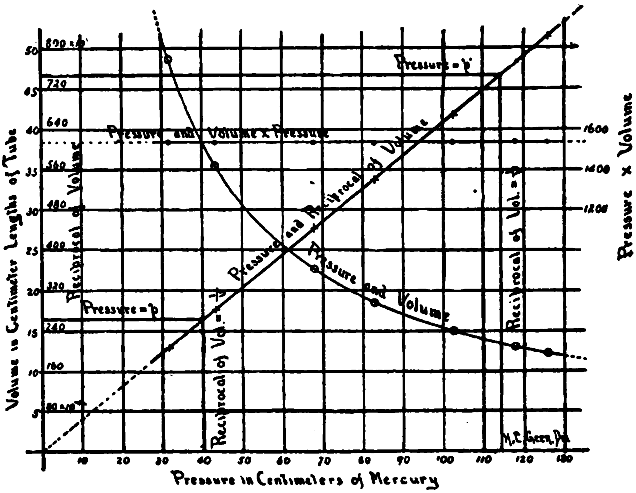
3. Put the scales along the axes together with the names of the quantities plotted. The arbitrary variable should generally be plotted along the horizontal or X axis.

4. Points indicating the experimental values to be plotted should be marked plainly by means of crosses, dots or dots surrounded by circles.

5. A smooth curve is then to be drawn so that it may best fit the observed points but not necessarily passing through them. This curve is to represent the continuous changes of the variables plotted. The deviation of points from the curve usually indicates errors of observation.

6. Give a title to each curve which usually will call attention to the variables plotted and the conditions under which the particular values were obtained.

Study carefully the following example of curve plotting.



RELATION OF PRESSURE AND VOLUME
(BOYLE'S LAW)

EXAMINATIONS: A written examination, covering all phases of the work in the laboratory, will be held at the end of each term and questions may be asked about any experiment performed at any time during the course.

Students electing more than one hour per term may be required to take an oral examination as well as the prescribed written examination.

NOTES ON UNITS.

The measurement of physical qualities always involves a unit upon which the measurement is based. It is said, for example, that a certain line is twenty five centimeters long. This involves the idea of a standard of comparison, and the standard is the centimeter, a unit of length.

The fundamental units of measurement in the system generally employed in physics are called the centimeter, the unit of length; the gram, the unit of mass; and the second, the unit of time. This system is called the C. G. S. system. For some purposes the fundamental units are not well adapted and other units which are multiples or submultiples of the fundamental units are used. These secondary units are called derived units.

Another system of absolute units is called the foot-pound-second system, in which the units of length, mass and time are the foot, pound, and second respectively, the unit of force based on this system is called the poundal, and is that force which will produce in a pound mass an acceleration of one foot per second for every second the force acts.

Among engineers so called gravitational systems of units are in general use in which a force unit takes the place of the unit of mass. In the English system the weight of a pound mass, about 32.2 poundals, is taken as the unit of force. This unit of force is commonly called a pound which often leads to confusing it with the unit of mass of the F. P. S. system, on which it is based. In the engineering system the unit of mass, which has no name, is 32.2 pounds.

According to Newton's second law of motion the acceleration produced in a body is directly proportional to the force acting on the body and inversely proportional to the mass of the body.

If the mass of a body be m and its acceleration a then the force producing the change of motion must be $f=ma$ from the above law. Now if this force be that due to gravitation then $f=mg$ where "g" is the acceleration due to gravity. The force with which a body is attracted by the earth is called the weight of the body, that is the weight of a body is a particular value of a force, $W=mg$.

From the above discussion it is seen that the ratio between the foot-pound-second system and the gravitational system is g the acceleration due to gravity.

The mass of a body is constant everywhere, but its weight varies from place to place.

Carefully read the paragraphs on units 5 to 8 and 11 to 14 inclusive. Read paragraphs 15 to 20 inclusive for a description of instruments which you may use for the measurement of lengths, studying carefully the principle of the vernier, paragraph 16.

PART I.

MECHANICS.

Experiment 1.

THE ESTIMATION OF TENTHS.

A COMPARISON OF THE INCH AND CENTIMETER.

References: Watson, §§ 11 and 15.

In engineering and other scientific work it is often desirable and sometimes necessary for accuracy of measurement to estimate scale readings to truths of the smallest divisions into which the scale is divided. Practice and good judgment are essential to good work.

The object of this experiment is to make some trials of estimating truths and to find the relation of the inch to the centimeter.

The distance between two points is to be measured in centimeters and inches.

Place a scale graduated in millimeters parallel with a line joining the two points. Do not place the end of the scale at either point. Read the position of the two points on the scale, taking care that the parallax be as small as possible. In general if a division mark of the scale be opposite one point the other point will be between division marks. Estimate the position of the second point to tenths of the smallest division; that is, to tenths of millimeters. Measure the distance between the points several times using different parts of the scale as starting points. Make one end of the line correspond to division marks in one set of readings, the other end of the line to correspond to division marks in another set, and neither end correspond to division marks in a third set.

In all cases put reading in the note book as soon as made. From these readings the length of the line is to be computed.

Then using the inch scale find the length of the line in the same manner, estimating tenths of the smallest subdivision of the inch.

Find the mean of the length of the line in centimeters and in inches and compute the number of inches to the centimeter, and also the number of centimeters per inch.

Referring to the text, find the errors of the results.

What are the sources of error in the determination and how may they be reduced to a minimum?

Tabulate results as follows:

USING METRIC SCALE.

Readings on Point A.	Readings on Point B.	Distance in cm.
27.50	43.78	16.28
32.23	48.49	16.26
38.81	55.10	16.29
41.17	57.41	16.24
53.49	69.76	16.27

Mean length in cm.

USING FOOT SCALE.

Readings on Point A.	Readings on Point B.	Distances in inches.

Experiment 2.

CALIBRATION OF INSTRUMENTS.

Reference : Watson § 12.

In scientific work where accuracy is to be attained the measuring instruments used must be studied and their errors investigated in order that the readings may be reduced to as nearly the true value as possible. These errors may be due to periodic or constant errors in graduation or both, or to the error of the zero point if that be always a point of reference.

For ease and rapidity of reduction of the readings to the approximately true values of the quantity measured a calibration curve is plotted.

The object of this experiment is to calibrate a spring balance, graduated in pounds, in terms of kilograms.

The spring balance gives a measure of the force with which gravity pulls on a given mass. The reading will vary from place to place on the earth's surface owing to the variation in the acceleration of gravity.

Suspend a spring balance at such a height that the pointer may be on a level with the eyes of the observer for any reading.

First, read carefully the position of the indicator on the graduated scale when there is no load.

Take readings of the indicator when 1 Kg. is added, and for every additional kilogram until the limit of the scale is reached, if it be a twelve pound scale. If the scale be a twenty five pound scale add two kilograms each time. Reduce errors due to parallax to a minimum by keeping the eye on a level with the indicator when making readings.

For each mass added make at least two readings. First lift the mass so that the pointer is raised two or three divisions, then carefully decrease the upward pressure to zero and take a reading. Next, exert a pressure from above and depress the pointer

two or three divisions, then slowly reduce the pressure to zero and read.

Correct the mean readings for the constant zero error, if there be one, and compute the value of the kilogram in pounds. Find the error of the mean value of the kilogram.

Tabulate observations as follows:

Reading of indicator for no load, zero error=

Load in Kgs.	Scale readings.	Mean readings.	Mean reading corrected for Zero error.	Pounds per Kg.

Mean value of pounds per Kg.

Plot a calibration curve using values of load for abscissas and mean scale readings (column 3) for corresponding ordinates.

Explain what the curve indicates. If the curve does not pass through the origin what does that fact indicate?

Experiment 3.

DETERMINATION OF THE GAUGE OF WIRE. MICROMETER CALIPER.

References: Watson, §§ 17 and 18.

Sizes of wire, twist drills and the thickness of sheet metal are often specified in commerce by gauge numbers. There being several wire gauges it is necessary to specify the one used; as the B and S gauge, the Birmingham gauge, or music wire gauge.

An instrument called the micrometer caliper is commonly used to determine the thickness of sheet metal and the diameter of wire. From these dimensions the gauge of the material is determined.

The micrometer caliper consists of a frame containing a nut fitted with a screw whose "head" or barrel is graduated around its circumference.

For accurate work the screw must have the threads parallel and the same distance apart. One revolution of the head advances the screw one division. The graduation of the barrel admits of an accurate reading of a small portion of a turn.

In making a reading always take care not to jam the nut, and to use as nearly as possible the same pressure.

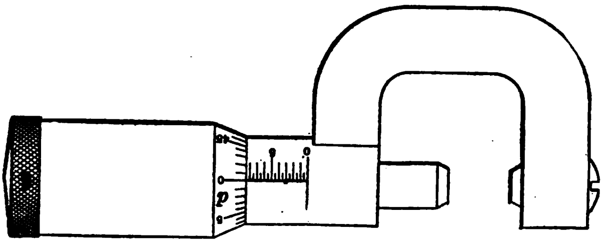


FIG. 1.—MICROMETER CALIPER

Determine the pitch of the screw and test for the zero error when the jaws are closed on each other, making ten readings.

Measure carefully the diameter of several wires, making at least ten readings on each wire moving the caliper to different points on the wire.

From the mean zero error and the mean of the reading on each wire determine the diameter of the wire, and the corresponding B. and S. gauge from tables. Find also the *Circular mils* in their cross-sections.

The electrical engineer uses units called the *mil* and the *circular mil*. One *mil* is a thousandth of an inch. One *circular mil* is the area of a circle one mil in diameter.

Find the average error in the readings on each wire.

Zero readings.	Reading on Wire No. 1.	Deviation from mean.	Reading on Wire No. 2.	Deviation from mean.

Mean= Mean Dev=
Mean Zero=
Diam. of Wire=
Gauge

Experiment 4.

DENSITY DETERMINATION FROM MASS AND VOLUME. VERNIER CALIPER.

References: Watson, §§ 15 and 16.

The mass of a body is defined as the amount of matter of which the body is composed.

The density of a substance is the mass per unit volume.

The object of this experiment is to determine the density of several substances from the respective masses and volumes, and to get experience in using the vernier caliper.

The masses are to be determined by means of the balance, and the volumes are to be found from the linear measurements.

(1) Find the mass of each body in grams; first putting the body on one of the scale pans then on the other pan, taking the mean as the final value of the mass.

(2) Find the dimensions of the body, using the vernier caliper, in centimeters and also in inches. Measure each dimension several times along various lines. If it be a cylinder find its diameter at six or more places, and its length along several elements of its surface.

In making readings with the caliper do not exert too much pressure, which may spring the jaws. If the jaws are not parallel always make measurements by bringing the points on the jaws which bear on each other when they are closed, to bear on the object measured. Determine the zero error of the instrument when the jaws are in contact, making a number of readings and taking the mean for the zero correction.

Correct the mean reading of any dimension for the zero error.

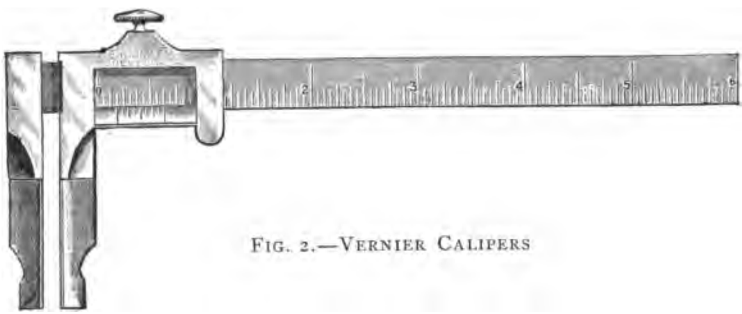


FIG. 2.—VERNIER CALIPERS

Reduce the mass to pounds weight and find the mass in grams per cubic centimeter, and also in pounds weight per cubic inch.

From the mean linear dimensions determined find the relation between the centimeter and the inch, the cubic centimeter and cubic inch.

Compare the densities and relations found with those given in tables.

Note. If the jaws of the caliper will not take in a dimension of an object use a centimeter and an inch scale to determine the dimension, reading the scale to the tenth of the smallest division.

Tabulate your data carefully.

Experiment No. 5.

A STUDY OF UNIFORMLY ACCELERATED MOTION.

References : Watson, §§ 30, 31, 32 and 35.

For the General Theory Study the Above Paragraphs in the Text.

An inclined plane down which a steel ball is allowed to roll is used to study uniformly accelerated motion.

Adjust the inclination of the plane so that the sphere, starting from rest, rolls about 320 centimeters in 4 seconds. This may be done by placing a marker 320 cm. from the initial position and changing the inclination until the ball passes the marker at the fifth click of an electro-magnet connected to a seconds pendulum, the sphere being automatically released on the first click. A metal block may be substituted for the marker and the inclination of the plane changed until impact takes place at the fifth click.

Take observations only when the ball starts rolling on the first click, and continues to roll without wobbling.

Set four markers so that they are successively passed by the rolling sphere at the ends of 1, 2, 3, and 4 seconds. Measure the distance of each marker from the proper initial point and record the distances. Remove the markers and make two more independent settings of the markers in order to get good averages. In making readings take care that any observation is not influenced by any preceeding observation.

The settings may be made by using a movable metal block and adjusting its position so that the sphere may strike it at the click of the sounder, starting with the block too high up the plane and moving it down gradually until the sounds coincide. Measure the distance passed through by the ball. Make another setting starting with the block too far down the plane moving it up gradually until the ball strikes the block

with the click of the sounder. Measure the distance as before. Do this for 1, 2, 3 and 4 seconds.

Tabulate data and results as follows :

DATA.		RESULTS.			
Time in Sec.	Total distance.	Acceleration.	Velocity at end of sec.	Velocity at middle of sec.	Distance passed over in the n sec.
1	24.7 25.3	50.0	50.0	25.0	25.0
2	99.7 100.3	50.0	100.0	75.0	75.0

In accelerated motion the velocity is constantly changing. If the motion be uniformly accelerated the changes of velocity in equal increments of time are equal. The velocity at any given instant may be taken as the average velocity over a very short interval of time. If ds is the space passed over in the time dt the average velocity for the time dt is $V_t = ds \div dt$, of which the particular instant is the midtime. [For the significance of dt see note in Watson's Physics at bottom of page 28.]

Give indicated numerical examples of computations.

Read carefully the directions regarding curve drawing in the introduction to the manual and also paragraphs 33, 34 and 35 in Watson's Physics.

Plot the following curves on the same sheet, using carefully chosen scales :

(1) Time in seconds as abscissas, velocities acquired as ordinates.

(2) Time in seconds as abscissas, accelerations acquired as ordinates.

(3) Time in seconds as abscissas, total distances acquired as ordinates.

(4) Square of time as abscissas, total distances acquired as ordinates.

Explain the method of determining the velocity at the middle of a second and also at the end of a second.

Define acceleration, uniformly accelerated motion.

From data and results as illustrated by curves draw conclusions with regard to motion down an inclined plane. These conclusions should state the relation between :

1. Velocity acquired and time.
2. Total distance traversed and time.
3. Acceleration and time.
4. Distances traversed in successive equal intervals of time.

Each of these conclusions should be stated in words, in symbols, and finally in symbols with numerical coefficients.

The results of this experiment will probably differ from ideal results which the student may be looking for. This difference is due to several causes : Errors of observation, (an error of .05 sec. in setting the marker at the end of the plane will correspond to a distance of about 8 cm), friction, air resistance, and wobbling. The motion down the plane is not ideally simple.

Experiment 6.

DETERMINATION OF SPRING CONSTANY AND g BY ELONGATIONS AND VIBRATIONS.

References : Watson, §§ 49–51, 59–61, 172.

1. To find the Spring Constant by elongations.

If a mass m is suspended from a spring and is allowed to come to rest it is in equilibrium under the action of two forces,

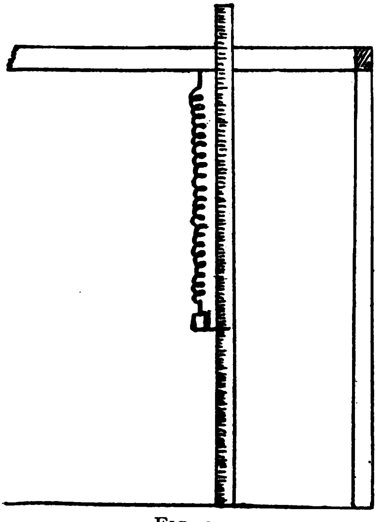


FIG. 3

the upward pull of the spring and the downward pull of gravity. Here the resultant force acting upon it is zero, (or it would not remain at rest). To specify its position we can fix a vertical meter stick beside it and by means of a pointer attached to m find the scale reading corresponding. If a greater mass is attached the spring will be stretched more, and the rest position will be lower. The reverse is true for a less mass. The rela-

tion between the stretching and the force acting on the bob m is that an increase in force produces a proportional elongation or increase in length. Let l represent the scale reading specifying any position of the bob, w the corresponding earth-pull, or *weight*, acting on the bob-mass m. To indicate that a certain scale-reading, weight, and mass correspond to one another we may use subscripts; thus l_1, w_1 and m_1 mean the scale-reading, weight, and bob-mass which correspond to one another. Then $l_2—l_1$, means the change in length, or elongation, of the spring when the weight is changed from w_1 to w_2 by changing the suspended mass from m_1 to m_2. The elongations and weight-changes being proportional, an equation may represent the relation thus:

$$K(l_2-l_1)=w_2-w_1.$$

The letter K stands for a constant multiplier, whose meaning is clear if the elongation $l_2—l_1$, happens to have the value one centimeter; then the equation stands $K=w_2-w_1$. In words K is the change in grams weight which produces an elongation of one centimeter. This may be called the spring constant which may be different for different springs.

The equation $K(l_2-l_1)=w_2-w_1$, is an algebraic statement of Hooke's Law for the spring. See Watson § 172.

To determine the value of K for a particular spring, suspend it from a bar with a mass on it sufficient to elongate it 2 or 3 cm. Clamp a meter stick beside it as in the figure. Bring the bob to rest and take the reading of the pointer. Add successively 10 or 20 grams at a time, and take the readings each time. As soon as taken, enter the data in your notebook in the following form and compute as shown.

TABLE OF DATA.

Obsn. No.	Grams Wt.	Scale-Rdgs. Cms.		Diff. Grams.	Diff. Cms.
1	99.0	51.21	6th-1st	108.5	12.63
2	111.5	52.79	5th-2nd	59.8	6.89
3	133.7	55.35	4th-3d	18.6	2.17
4	152.3	57.52	Sums	186.9	21.69
5	171.3	59.68	$K=\frac{186.0}{21.69}=8.614$		
6	207.5	63.84			

Plot a curve with gram-weights as ordinates and scale readings as abscissas. It should be a straight line with its slope nearly equal to the value of K computed from the data. Why is it straight? Does it pass through the origin? Why?

11. To find the Spring Constant (in Dynes) by Vibrations, and the Value of g.

Suspend a known mass m from the same spring. The mass will rest by the scale at a position which may be called l_0. If now it be pulled straight down and let go it will vibrate up and down for a while, travelling gradually shorter distances until it comes to rest again at l_0. Call its position at any instant while in motion l. Its displacement from the rest position is then $l-l_0$. The force acting on it is the resultant of the spring-pull, upward, and the earth-pull, downward; but is not zero except when passing through its position of equilibrium, since the body moves with changing speed. (Newton's Law II.) At l_0 the spring-pull balances the earth-pull w. Below l_0 the spring-pull is in excess by $-K(l-l_0)$. Above l_0 the earth-pull is in excess by a like amount. The resulting force acting at l is therefore in grams-weight $-K(l-l_0)$, and in dynes $-gK(l-l_0)$. This force is proportional to the displacement from l_0 and directed opposite to it.

When a body has simple harmonic motion its acceleration is proportional and opposite to the displacement.

$$\propto = \omega^2 x = -\frac{4\pi^2}{T^2} x. \quad \text{(See Watson § 51).}$$

By Newton's Second Law the resultant force acting on a body is equal to its mass multiplied by its acceleration. In the case of S. H. M. force $= mx = -\frac{4\pi^2 m}{T^2} x$, measured in dynes. If we put $(l - l_0)$ instead of x, force $= -gK(l - l_0) = -\frac{4\pi^2 m}{T^2}(l - l_0)$, or $\frac{4\pi^2 m}{T^2} = gK$. Here m and T are found by experiment, and K is known from Part I ; hence g is determined.

To find the period, set the bob in vibration with an amplitude of about 5cm.; note the time of starting, and the time of the 10th, 20th, . . . 50th returns to the starting point. Tabulate and compute the periods for four bobs as shown below. Then compute g using the value of K found in Part I. Results will be more accurate if the mass of the spring is taken into account. Why? Add to each bob-mass ⅓ the mass of the spring.

Plot a curve with corrected bob-masses m as ordinates and squares of periods, T^2, as abscissas. It should be straight, with a slope $\frac{Kg}{4\pi^2}$. Compare the value of g found from this slope with that found by computing. A considerable variation from $g = 980$ may be expected, amounting to perhaps 5%.

TABLE OF DATA.

No. Obsn.	No. Return.	Time of Return. h.	m.	s.		Vibns.	Time. Sec.
1	0	11	30	24	6th-1st	50	49.
2	10		30	35	5th-2nd	30	29.
3	20		30	44	4th-3rd	10	9.
4	30		30	53	Sums	90	87.
5	40		31	4			
6	50		31	13	$T = 87 \div 90 = 0.967$ secs.		

The above shows the method of computing T from the observations. A set made at the same time as the observations in the table in Part I gave the following values of m, T and T^2:

m	99.0	111.5	133.7	152.3
T	0.693	0.7415	0.8035	0.852
T^2	0.481	0.549	0.646	0.726

Combining with these the value of K given in Part I, 8.614, the average value of g found was 1019.

Read the references, and write in your notebook the following definitions, etc.:

Simple Harmonic Motion (using the circle diagram), displacement, phase, period, frequency, linear and angular velocity, acceleration, dyne and gram-weight. Give the relation between these last two. What is Hook's Law?

If a body is subject to forces that act according to Hook's Law, what must be the nature of its motion? Why?

When the bob is vibrating, where are its velocity and acceleration greatest and least? Why? How does change in amplitude affect its period?

When force is expressed by mass × acceleration, why is it measured in dynes?

What is the meaning of g?

Experiment 7.

RELATION OF FORCE, MASS AND ACCELERATION. NEWTON'S LAWS.

References: Watson §§ 58, 59, 60, 61, 62, 63.

If equal masses be attached to the two ends of a cord passing over a pulley as nearly frictionless as possible, it will be found that unless started the masses will not move and that if set in motion the motion will become gradually slower owing to the friction of the pulley. If just enough excess mass m, be added to one of the large masses so that the excess force acting on one side is just equal to the slight retarding force of friction,

and the masses be given a small motion, the motion will be found to be uniform since all the forces are balanced.

Now, if a still greater mass be added to the one side and the system be released there will be an unbalanced system of forces, and a uniformly accelerated motion will result. The force producing the motion is that unbalanced force due to the action of gravity on the second added mass which, from Newton's second law of motion, is equal to the added mass times the acceleration of gravity. It may be expressed symbolically as $f_2 = m_2 g$.

Let m_1, be the mass added to overcome frictional forces. Since no acceleration is produced the force $m_1 g$ does not produce motion and is therefore not considered.

Let M and M be the masses on the two ends of the cord and M_0 be the equivalent mass of the pulley.

Again from Newton's second law the total mass moved $(M+M+M_0+m_1+m_2)$ times the acceleration produced (a) must be equal to the accelerating force which we know to be $f_2 = m_2 g$.

$$\therefore m_2 g = (M+M+M_0+m_1+m_2)\, a$$

If all the masses be known and the acceleration be observed, g the acceleration of gravity may be found.

The relation connecting the mass, acceleration and force is

$$f = ma$$

$$\text{or } a = \frac{f}{m}.$$

which indicates that the acceleration produced in a system varies directly with the force applied and inversely as the mass acted on.

The object of this experiment is to determine whether the above relation holds and to find g the acceleration of gravity.

Experiment. Pass a cord over a pulley and suspend a mass of 1 Kg from each end. Add enough mass to one side to overcome pulley friction. Then add enough mass to the same side so that when the system is released the heavier side will strike a support a meter or two below in a given number of

seconds. Make a note of the masses used and the distance passed through. Repeat twice more as a check and use the mean in computation.

Now add 500 grams to each end of the cord and determine again the distance passed through in a known period of time, making check readings.

Add another 500 grams to each side and repeat again.

Make two other sets of observations in the same manner as the above starting with 2 Kg. on each side then 3 Kg. on each side, using the same three accelerating forces.

Arrange data and results as follows:

$M_0 = 40$

M.	m_1	m_2	Total Mass.	Time of Fall.	Dist. passed over.	Acceleration a	g.
2000	10	50	4100	5	148.3 150.2 149.5		
2000	10	100	4150		149.3	12.–	964–

In each set compare the values of m_2 with their respective a's. For the same m_2 compare the values of a corresponding to different "Total Masses."

An Atwood's machine may be used to show the relations given in the discussion above using convenient masses and accelerating forces.

For either method plot a curve using total masses as abscissas and the reciprocals of corresponding accelerations for a given accelerating force as ordinates. The slope of the curve is equal to the reciprocal of the accelerating mass m_2 times g. Using this fact find g from the curve.

Experiment 8.

EQUILIBRIUM OF FORCES.

References : Watson §§ 65, 66, 71 and 72.

Three concurrent forces are in equilibrum when they are parallel and proportional to the sides of a triangle and in the directions in which these sides are successively passed over in going round the triangle.

1. Cause three forces to act at a common point by means of weights attached to cords which pass over pulleys to the common point. (See diagram). Move the intersection of the cords up and down, to the right and to the left, and finally leave it at the point where you think it would come to rest if there were no friction at the pulleys. (To get the best results, the three angles should not be greatly different.)

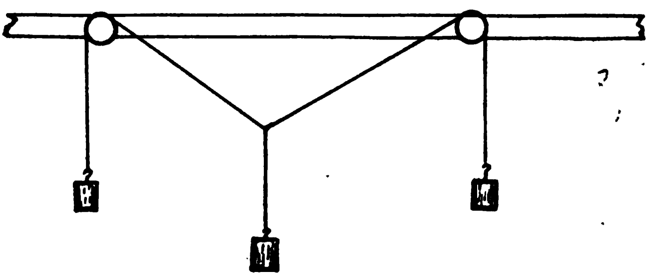


FIG. 4

Measure and record the three forces; measure and record the three angles. Repeat all observations for two different combinations of forces, using a different ratio of loads in each case.

From a common point draw heavy lines representing to scale the three forces in direction and magnitude. Use a whole page in your note-book for each diagram. Put an arrow head

at the end of each of these lines showing the direction in which the force acts. On any two of these lines complete a parallelogram by drawing light lines. Draw the diagonal of this parallelogram and compare its magnitude and direction with the remaining line representing a force.

From the results of this experiment, draw a general conclusion.

II.

Cause four forces to act at a common point, by means of weights, cords and pulleys, or by means of cords and spring balances. Measure angles, and observe forces recording them at once in your note book as in part I. As before, draw heavy lines representing in direction and magnitude the four forces. Divide these lines into pairs, and complete a parallelogram on each pair. Compare the diagonals of these two parallelograms. Draw conclusions.

Experiment 9.

A STUDY OF PARALLEL FORCES AND THE PRINCIPLE OF MOMENTS.

References: Watson, § § 68, 69, 70 and 75.

When a body is acted on by several forces, two conditions are necessary in order that no motion of translation or rotation shall take place, namely:

The resultant of all the forces in any direction must be zero; otherwise there is a translatory motion.

The sum of the torques (moments of all the forces) about any point arbitrarily chosen as an origin or center of moments must be zero, or a rotation will take place.

I.

Balance a straight bar on a knife edge to find its center of mass, as at B. Determine its mass B. Then suspend the bar horizontally by means of spring balances as shown in the figure.

From any point along the bar as at A, a known mass is sus-

pended. Assume any point O as a center of moments. Then for equilibrium the following expressions must hold, assuming forces acting downward as positive and those acting upward as negative, clockwise moments as negative and contra-clockwise moments as positive ;

$$C + B+A-X-Y=o \quad (1.)$$

$$C \;+Aa+Bb-Xx-Yy=o \quad (2).$$

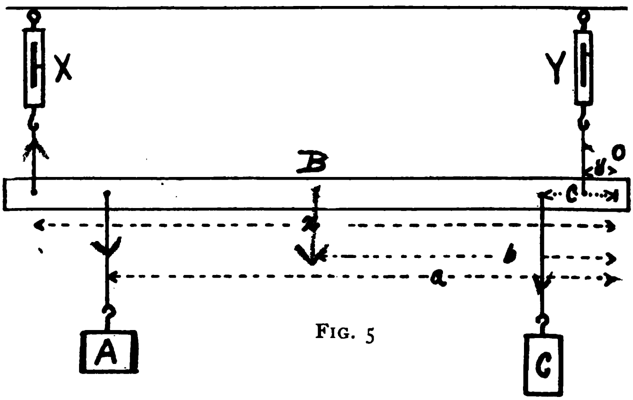


FIG. 5

Measure the distances a, b, and so on. Observe B, A, X, Y, etc., and reduce them to the same units. Verify the above relations of forces and moments of forces in equilibrium.

II.

Mount the gate (Fig. 6) or derrick (Fig. 7) in a vertical plane as shown in the figure. With a given mass F_1, adjust the apparatus until the bar supporting the mass F_1, is as near horizontal as possible. Find the mass and the center of mass of the apparatus. Observe the value of the force F_2. Express all forces in the same units. Having the three known forces find the magnitude and direction of the fourth force, by means of a large accurately drawn force polygon to scale.

Draw accurately to scale a large plot of the apparatus, showing the four forces drawn to the same scale as used in the force polygon.

Find the sum of the moments of all the forces first about the point O and then about any point P outside the figure. Com-

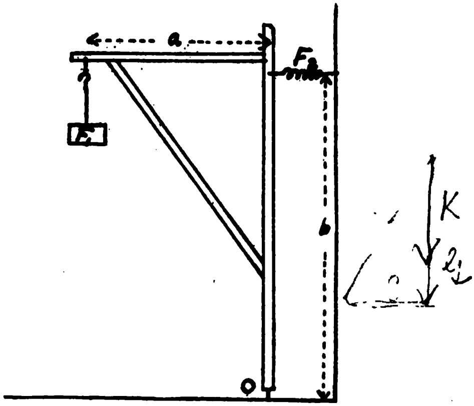


FIG. 6

pute the percentage error of the results and state the principles on which the computations are based.

Does any moment appear in the last computation that did not appear in the first? Why?

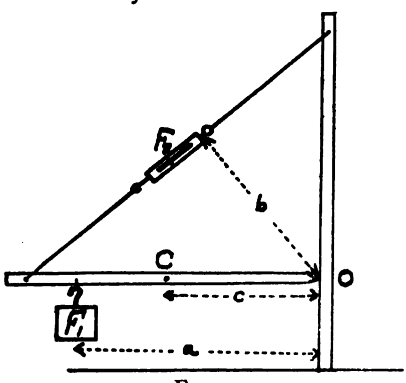


FIG. 7

Tabulate your data and results carefully.

Make two more sets of observations changing the positions of

the suspensions and suspended masses. In one of these use two suspended masses. In at least one case make a or c either greater or less than x or y, and assume the center of moments O at some point other than the end of the bar. Verify the relations for equilibrium as before.

Tabulate your readings and draw a diagram to scale representing the forces and lever arms.

Experiment 10.

WHEEL AND AXLE.

RELATION BETWEEN APPLIED FORCE AND FORCE OVERCOME.

References: Watson, §§ 89, 90, and 91.

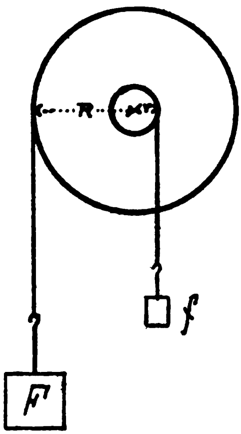


FIG. 8

A cord to which a weight is attached passes over the axle of a wheel and axle, and is fastened to it. This weight is the force overcome, call it F. Over the wheel passes a cord to which is attached a smaller weight. Determine the least value of this smaller weight necessary to maintain the larger weight in uniform upward motion when started; call this force f_1. In like manner determine the force which will just allow the weight to fall with uniform motion when started; call this force f_2. The mean of these two forces gives the applied force which would be required if there were no friction. Explain why.

Measure the radius of the wheel and of the axle, also the corresponding distances moved by the two forces.

Represent in direction and magnitude all the forces acting on the wheel and axle by a carefully drawn diagram.

Tabulate data and results as follows:

Diameter of wheel $= 2R =$
" " axle $= 2r =$
Distance moved by $F = L =$
" " " $f = l =$

Wt. lifted $=F$.	Force applied.			F/f	l L L/l
	f_1	f_2	Mean f		
1 kg.	218 g.	155 g.			

Draw conclusions and show that the same conclusion might be deduced from the principle of torque and equilibrium.

NOTE. The word "power" used in the text must not be confused with the term meaning the rate of doing work. In this case it means the working force. See paragraph 89 in the text.

Experiment 11.

THE PULLEY AND PULLEY SYSTEMS.

EFFICIENCY OF A PULLEY SYSTEM.

References: Watson, §§ 74, 89 and 92.

Two pulley blocks each containing one or more wheels called sheafs, are often used as a mechanical device in which a small force acting over a comparatively large distance overcomes a large force acting over a small distance.

The cord or rope to which the working force is attached passes in turn over the sheafs of the two pulleys and has one end fixed to a pulley block. If the sheafs were frictionless the tension in all parts of the cord would be the same and the weight lifted would be equal to the number of parts of cord connecting the two block multiplied by the tension in the cord. In practice

these conditions are not fulfilled on account of the weight of the block to which the weight to be lifted is attached and to the friction of the sheafs on their axles.

The efficiency of a system is the ratio of the useful work done to the amount of work done on the machine.

Suspend a weight of four or five hundred grams from the movable pulley block.

Place enough mass in the pan at the free end of the cord so that it will move downward with a uniform motion; call this force f_1. The force f_1, must then be sufficient not only to put the system in equilibrium but also to overcome the friction of the machine.

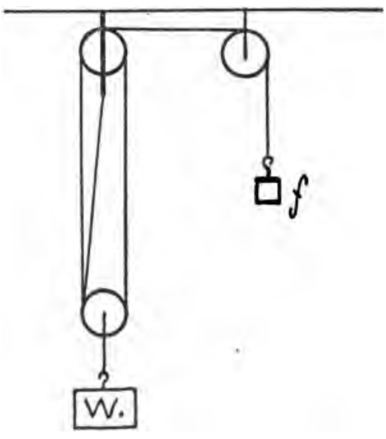


FIG. 9

To eliminate the amount of force necessary to overcome friction, decrease the mass on the free end until that end will move upward with a uniform speed; call this force f_2.

Then f is equal to the force necessary to produce equilibrium minus the force necessary to overcome friction.

Therefore the force necessary to produce equilibrium is

$$\frac{f_1 + f_2}{2} = f.$$

The weight of the pan is included in f.

Find the force f necessary to balance four different weights at w.

Find the relative distances passed through by the working force f_1 and the load w.

Remembering that the several values of f_1 are those necessary to operate the machine as a machine for doing work, find the efficiency of the machine for the different loads.

Draw a diagram showing the forces acting.

Arrange data and results as follows:

Load w.	f_1.	f_2.	$\frac{f_1+f_2}{2}=f$.	Dist. passed over by w.	Dist. passed over by f.	efficiency %

Draw the following curves:

(1) Use ws as abscissas and corresponding fs as ordinates.

(2) " " " " " % " "

Discuss curves.

EXPERIMENT 12.

THE INCLINED PLANE.

RELATION BETWEEN APPLIED FORCE AND WEIGHT LIFTED.

References: Watson, §§ 89 and 93.

A weight w rests on an inclined plane whose height is h and whose length is l. Determine the force parallel to the plane by means of a weight attached to a cord passing over a pulley, which will be just sufficient to maintain uniform motion up the

plane when started by the hand; call this force f_1. Now determine the force which will allow uniform motion down the plane; call this force f_2. The mean of these two forces is the applied force which would be required if there were no friction;

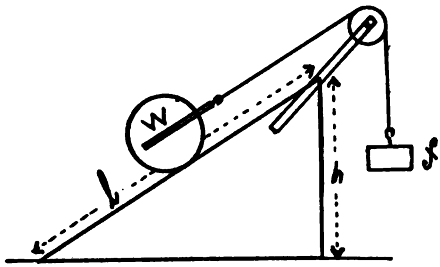


FIG. 10

call this force f. Measure the height and length of the plane. Make observations for three different inclinations of the plane.

Tabulate data and results as follows:

w=weight raised.

Force Applied.			Height of plane=h.	Length of plane=l.	$\frac{h}{l}$=sin ϕ	$\frac{f}{w}$
f_1	f_2	f				

Plot a curve using values of sin ϕ as abscissas and corresponding values of f as ordinates. Plot an efficiency curve using values of w as abscissas and % efficiency as ordinates. (See Exp. 11). What do the curves show?

Construct a diagram illustrating all forces acting on the weight in direction and magnitude. Draw conclusion. Show that the same conclusion can be drawn from the principles of force and equilibrium.

Experiment 13.

THE BALANCE.

References : Watson, §95.

Ames & Bliss, Experiment 11.

The general theory of the balance as given in Watson's Physics should be thoroughly understood before performing the experiment.

The experiment consists in weighing some masses, and determining the ratio of the lever arms of the balance.

The balance to be used is not considered a sensitive one but it will fill the wants of the experiment.

In making weighings do not allow the arms to swing violently. Always put masses on the scale pans when they are resting on the table on which the balance is supported.

To make a weighing.—With no mass on either scale pan, raise the pans off the support and allow the balance to vibrate so that the pointer does not pass beyond either end of the graduated scale near the end of the pointer. Air currents affect the vibration of the balance and therefore should be eliminated.

Determine the zero point by the method of vibrations. Allowing the pointer to vibrate over the scale take readings on the turning points, estimating tenths of divisions and assuming the zero of the scale at the extreme long mark to the left. Take one more turning point on one side than on the other. Find the average reading on each side. Find the mean of these two averages, which will give the zero reading of the balance.

The following is an example of a zero determination:

Scale Readings.

Left	Right	
2.8	17.0	16.6
3.2	16.6	3.0
	16.3	
2 | 6.0		2 | 19.6
	3 | 49.9	
3.0		9.8—Zero
	16.6	

Make two more determinations of the zero of the balance. A good agreement among the zero determinations indicates that the balance is in good order.

To determine the mass of a body. Place the body on one scale pan and some weights on the opposite pan. Raise the central knife edge by means of the key to see if the weights added are about right. If they are not, lower the knife edge, change the weights and try again. Continue the operation until a combination of weights is found that will not carry the pointer off the scale. Then make readings of the turning points as before, to determine where the pointer would come to rest. In general this rest point will not coincide with the zero previously determined.

To find what weights would bring the pointer to the proper zero add 0.1g to the weights and find the rest point by the method of vibrations. The difference in the two rest points will give the change in reading for a change of 0.1 gram.

Knowing the change of rest point for 0.1g and the desired change to bring the rest point to the zero, the amount of weight that must be added to or taken from the weights to make the proper balance is easily computed.

This method assumes that there is no shift of the zero when the balance is loaded and that the balance arms are equal.

No correction is made for the buoyancy of the air.

DOUBLE WEIGHINGS AND RATIO OF BALANCE ARMS.

To eliminate errors due to unequal arms the mass may be weighed first on one pan, then on the other. Let l_1, and l_2 be the lengths of the two balance arms. Let w_1 and w_2 be the weighings when x the unknown is at the end of the arms l_2 and l_1 respectively.

For the first weighing.

$$xl_2 = w_1 l_1 \quad (1).$$

When x is placed in the other pan,

$$xl_1 = w_2 l_2 \quad (2).$$

Multiplying these two equations together and solving for x we have

$$x = \sqrt{w_1 w_2}$$

If the arms are very nearly the same length, the arithmetic mean of the two weighing is accurate enough for most purposes.

If equation (1) be divided by equation (2) the following expression showing the ratio of the balance arms may be obtained :

$$\frac{l_2}{l_1} = \sqrt{\frac{w_1}{w_2}}$$

Find the ratio of the balance arms using the method above described. Making two determinations using different masses.

Experiment 14.

X

COEFFICIENT OF FRICTION.

References : Watson, §§ 96, and 99.

The object of this experiment is to find the coefficient of kinetic friction between two surfaces and show that it is independent of the pressure.

The coefficient of friction is defined as the ratio of the tangential force required to produce uniform motion, to the normal pressure. The coefficient depends on the nature and condition of the surfaces. On that account do not touch the surfaces with the hands because it will change the condition of the surfaces and consequently the coefficient will be changed.

Put a mass of 2 Kg on the block, then add enough mass to the hanger to produce uniform motion when the block is started by hand. Take readings for masses of 2, 4, 6, 8 and 10 Kg. Taking account of mass of block compute the several values of the coefficient.

Plot a curve using tensions in cord as ordinates and corresponding masses for abscissas. Consider the pulley as frictionless. Draw conclusions and discuss the curve.

Mass of Block=.

Mass of block plus added mass.	Force producing motion in grams wt.	Coefficient of friction, μ.

Experiment 15.

WORK AND POWER.

References: Watson, §§ 74, 75, 76, 78 and 102.

(A) *Work against gravity.*

Weigh yourself, measure distance from first to third floor, climb the stairs and observe the time required. State whether the stairs were climbed very quickly, quickly, moderately, slowly, or very slowly.

Tabulate data and results as follows :

	English Engineering units.	French Eng. units.	C. G. S. Units.	M. K. S. Units.
Weight	134 lbs.	Kg.	dynes.	dynes.
Vertical Distance	40 ft. 7 in	M.	cm.	meters.
Time	58 sec.	sec.	sec.	sec.
Work Done	ft-lb.	Kg-m.	ergs.	Joules
Power expended	$\frac{\text{ft-lb.}}{\text{sec.}}$ H.P.	$\frac{\text{Kg-m.}}{\text{sec.}}$ F.H.P.	$\frac{\text{ergs.}}{\text{sec.}}$	Watts

(B) *Work against friction. The Friction Dynamometer.*

A strong cord passes around the groove of a balance wheel. Its two ends are fastened to two spring balances, the latter being fastened to a solid support. One end of the cord may have a known weight suspended from it in place of a spring balance. If the balance wheel is turned rapidly the tension of one branch of the cord will, on account of friction, be greater than that of the other. The amount of work done will be the same as in the case of a fixed wheel and a moving cord. If l is the distance moved by the cord (or by the rim of the wheel if the cord

$W = Fd$
$F = F_1 - F_2$

is fixed) then the positive work is $F_1\, l$ and the negative work is Fl. The net work on the wheel is $(F_1 - F_2)l$. If the wheel makes N revolutions we have $l = 2\pi r N$ and the work will be

$$W = (F_1 - F_2)2\pi r N = G\Phi.$$

in which G is the resultant torque and Φ is the angle turned through expressed in radious.

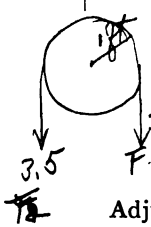
Observe the tensions as indicated by the two balances both when the wheel is at rest and when it is in uniform motion. Count the number of revolutions in 1 min., observing F_1 and F_2 at intervals of 10 seconds. Reduce data to consistent units.

Tabulate data and results as follows :

$F_1 = F_2 =$ with wheel at rest.

28 = $2r =$ diameter of wheel= cm.= in.

Worker.	Rev. in 1 min.	F_2	F_1	Work Done.	Power.		
					$\frac{\text{ft. lbs.}}{\text{sec.}}$	H. P.	Watts.
	44	2.2	18				



Experiment 16.

ACCELERATION OF A FREELY FALLING BODY.

References : Watson § §35 and 108.

Adjust the height of an electromagnet so that it takes just three half seconds for the "keeper" to fall to the floor. Measure the distance fallen. Repeat, making the time required two-half seconds, and one-half second. Repeat each of these measurements twice.

From the average distance traversed in three-half seconds compute the acceleration of gravity. Do the same for two-half seconds and for one-half second.

Derive the formula used for determining the acceleration.

Draw a curve using time as abscissas and distances traversing in 1, 2, and 3 half seconds as ordinates. From the same origin and to the same scale draw a curve using velocities attained and time as coördinates. Discuss the curves and their intersection.

Show how computations were made.

Time	Distance fallen.	Computed acceleration of g.	Velocity attained.
1.5			
1.0			
.5			

Experiment 17.

THE SIMPLE PENDULUM.

References: Watson, §§ 112, 113 and 114.

The object of this experiment is to verify the relation existing between the periodic time and length of the simple pendulum and to find the acceleration of gravity g. The relation is $T = 2\pi\sqrt{\frac{l}{g}}$. Suspend a metal sphere by a long fine cord from a solid support. Set it to vibrating through a *small angle*. Determine the periodic time for four different lengths, varying from about 20 cm. to the greatest length convenient using nearly equal intervals.

To determine the periodic time observe the time in hours, minutes, and seconds at which the pendulum passes through its mid position in a given direction; then, counting the transits through the mid position in the same direction take the time of the 50th, 100th, 150th, 200th and the 250th transit.

For the longer length the observations may be made for every 25 transits taking the same number of observations.

Find the value of T for each set and take the mean as the proper value for the given length.

Measure the length of the simple pendulum several times using the mean value for each length taken. The length to be measured is from the support to the middle of the ball.

Tabulate data and results as follows :

Length of Pend.	Time of transits to right.				Time of n vibrations.			Periodic Time T	T^2	$\frac{l}{T^2}$	g
		h.	*m.*	*sec.*		*min.*	*sec.*				
35·75	0	9	20	35	250— 0=	5	1	1.202	1.445		
	50	9	21	36	200— 50=	2	58				
	100	9	22	33	150—100=	1	2				
	150	9	23	35	450=	8	61				
	200	9	24	34							
	250	9	25	36							

Plot two curves using values of l as abscissas ; for one curve use values of T as ordinates, and in the other curve values of T^2 as ordinates.

Discuss curves and data. Show by diagram the forces acting on the pendulum when displaced from its mid position and discuss the force system.

Experiment 18.

UNIFORM CIRCULAR MOTION AND ACCELERATION TOWARD THE CENTER.

References : Watson § § 42 and 85.

When a particle moves in a circle there is a tendency for it to move off in a straight line. There must be a force acting constantly to cause the particle to move in a circular path.

Suppose the angular velocity ω be uniform. Then the force causing the particle to move in a circular path must be either toward or from the center. If the force acted in any other direction there would be a component of the force acting at right angles to the radius joining the particle to the center of the circle and its motion would be accelerated. The particle does

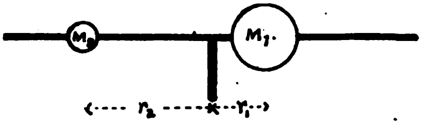


FIG. 11.

not move away from the center, therefore the force must be toward the center.

The expiession for the acceleration of a particle moving at a uniform angular velocity in a circular path is :

$$a = \frac{v^2}{r}$$

where v is the speed or tangential velocity and r is the radius.

Since $f = ma$ the force acting toward the center is $f = \frac{mv^2}{r}$

But $v = r\,\omega$

therefore $f = m\,r\,\omega^2$.

To show that f varies with r.

Let two masses m_1 and m_2 be mounted on a bar which revolves in a horizontal plane. Consider that the masses may slide on the bar without friction.

If the bar be rotated there will be forces acting to cause the masses to move from the axis with a force equal and opposite to that necessary to hold them at a fixed distance from it. These forces will be

$$f_1 = m_1\,r_1\,\omega_1^2$$
$$f_2 = m_2\,r_2\,\omega_2^2$$

Since the bar is rigid the angular velocity w will be the same for both masses.

If a light cord fasten the two masses together, in general they will move in the direction of the larger force. If the values of r_1 and r_2 be properly chosen the two forces will be equal and since they are in opposite directions no slipping along the bar will take place when the bar is rotated about a vertical axis.

Then $f_1 = f_2$,

or $m_1 r_1 \omega_1^2 = m_2 r_2 \omega^2$,

and $m_1 r_1 = m_2 r_2$,

from which $\frac{r_1}{r_2} = \frac{m_2}{m_1}$

that is, the radii for no sliding motion are to each other inversely as the masses.

Experiment:—Fix the relative positions of the two masses a few centimeters apart by means of a small wire. Revolve the bar about a vertical axis, slowly at first and adjust the positions of the masses until no radial motion takes place. Gradually increase the angular velocity, shifting the position of the masses when necessary until a very high angular velocity may be attained with no radial motion. This is necessary to reduce to a minimum errors due to friction of the masses on the rod.

Stop the machine and measure r_1 and r_2.

Repeat the experiment with the masses at different distances apart, making four sets of observations.

Find the masses of m_1 and m_2 and show the numerical relations among the observations.

Care must be taken that the bar rotates in a horizontal plane.

Experiment 20.

BOYLE'S LAW.

References: Watson, §§ 130, 132–134.

The object of this experiment is to investigate the relation between the pressure and volume of a constant mass of a perfect gas, the temperature remaining constant.

Obtain the atmospheric pressure from the barometer, which may give readings in inches. Reduce the reading to centimeters of mercury.

Experiment:—Close the tap at C and pour in mercury until its level is about four or five centimeters above the lower end of the scale. Then close the tap at B thus tapping off a certain volume of air in the short tube. Read the mercury level in both tubes. Pour mercury quite slowly into the long tube until the height of the surface in that tube has been raised by fifteen or eighteen centimeters (15 or 18 cm.). Read the level of the mercury in both tubes. Proceed in this manner until the long tube be filled with mercury to near the top of the scale. The readings obtained will be for pressures greater than one atmosphere because the pressure at the upper mercury surface in the short tube will be the same as for a corresponding level in the long tube, on basis of hydrostatic pressure. The pressure at this point will be equal to the weight of the superimposed mercury plus the atmospheric pressure.

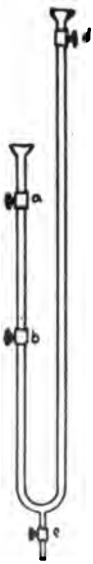


FIG. 12

For pressures less than atmospheric open the stop cock at B, thus opening this tube to the air. Adjust the common mercury level in the two tubes until it is 8 or 10 cm. below the tap B. Then close the tap B. After having read the common mercury level, carefully open the valve C allowing mercury to run into a vessel placed beneath the opening, until the level in the open tube has dropped 5 or 6 cm. Close the valve C and read as before. Then open C again allowing the level to drop 5 or 6 cm. and read. Get five or more readings.

In the closed tube the pressure will be less than atmospheric.

Be very careful with the apparatus. Pour in mercury slowly. Wait between readings a few minutes in order that the temperature of the gas in the closed tube may become constant. Explain why a change of temperature will take place.

When the experiment is finished carefully draw off the mercury.

Plot curves for pressures both above and below the atmospheric pressure as follows: Use pressures for ordinates and volumes, proportional to lengths of column of air inclosed tube, as abscissas for one set of curves; and for another set use the reciprocal of pressures as ordinates and volumes as abscissas. Discuss curves. Reading in both tubes when level is the same=

Barometer reading, inches= cm.=

Closed tube readings.	Volume (Proportional to lengths.)	Open tube readings.	Dif. of Hg levels.	Pres. in cm. of Hg.	P. V.

Experiment 21.

DENSITY OF LIQUIDS.

HARE'S METHOD.

Reference: Watson, § 145.

In finding the relative density of two liquids that mix, a method devised by Hare is easily applied. The principle of the experiment is that the pressure exerted by a liquid is proportional to the height of the liquid, to its density, and to the acceleration of gravity, $p=hdg$ where p is the pressure, h the height of the liquid column of density d, and g is the acceleration of gravity.

Hare's method makes use of the fact that the ratio of the densities of two liquids which exert the same pressure is equal to the inverse ratio of the heights.

An inverted U tube, the bend of which is connected to a suction pump, is mounted vertically. A scale is fastened to the frame between the two tubes which measures distances from the lower ends of two wires A A. Before performing the experiment clean out the tubes by drawing distilled water into them, then force air through them until dry.

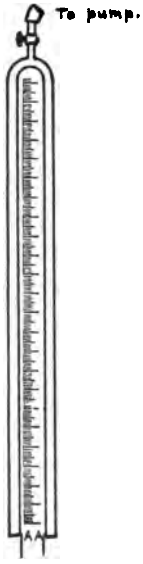


FIG. 13

Place two beakers containing the liquids whose densities are to be compared at the lower ends of the tubes and draw the liquids up the tubes until one of them is near the top of the scale. Close the connection to the pump, and by means of a pipette regulate the height of the liquids in the two beakers until their surfaces are at the lower ends of the rods A A. Read the respective heights of the liquids in the two tubes.

Allow enough air to enter the upper end of the U tube to lower the surfaces of the liquids by about ten centimeters.

Adjust the level of the liquids in the beakers and make a second reading.

Make at least six readings like those described above, comparing a number of substances with distilled water, or with a substance of known density.

Note the temperature of the liquids and find their specific gravities.

Prove that $\frac{d_1}{d_2} = \frac{h_2}{h_1}$.

Experiment 22.

SPECIFIC GRAVITY.

HYDROMETERS.

References : Watson, §§ 127 and 148.

Study the references given above for the theory of the hydrometer.

The experiment consists in finding the specific gravity of several liquids by means of both the variable immersion hydrometer and the Nicholson's hydrometer.

Find the specific gravity of a solid by means of the Nicholson hydrometer.

Experiment 23.

SPECIFIC GRAVITY OF SOLIDS NOT SOLUBLE IN WATER.

Reference : Watson, § 127.

(1) Solid ; specific gravity greater than unity.

Weigh the solid in air, then weigh it suspended in water.

State Archimedes Principle and derive a formula for specific gravity.

Why does the body lose weight when weighed in the liquid ?

Tabulate data as follows :

Substance.	Wt. in air.	Wt. in water.	Loss in water.	Sp. Gr.

(2) Solid ; specific gravity less than unity.

Weigh the solid in air. Weigh a "sinker" in water, and find the combined weight of sinker and solid in water.

Derive a formula for specific gravity for this case.

Substance.	Wt. in air.	Wt. of sinker in water.	Wt. of solid and sinker in water.	Loss of wt. in water.	Sp. Gr.

Experiment 24.

SPECIFIC GRAVITY OF SOLIDS AND LIQUIDS BY MEANS OF JOLLY BALANCE.

References : Watson, § 146.

If a bottle be carefully cleaned, then filled with distilled water of known temperature and weighed, the volume of the bottle may be determined ; the weight of the bottle being known.

If the bottle now be filled with some other liquid, at the same temperature, and weighed, the weight of the liquid may be determined. Since the volume of the liquid and that of the water are the same the specific gravity may be found very easily.

Bottles made for this particular purpose are called pyknometers or specific gravity bottles.

The specific gravity of a solid which is not acted on by water is easily determined.

Weigh the empty bottle. Place the solid in the bottle and weigh again. Fill the bottle with distilled water being careful to get all air bubbles out and find the weight of the combination. Finally find the weight of the bottle filled with distilled water. From these data the specific gravity of the metal may be determined.

Show how computations are made in each of the above cases.

The Jolly Balance.

The weighings in this experiment are to be made by means of a Jolly balance.

The Jolly balance is fundamentally a coiled spring fastened at one end and free at the other. To the free end is attached a scale pan in which the substances to be weighed are placed. The spiral spring follows Hook's law, that is, equal increments of force acting on the spring produce equal increments of length. (See Exp. 6.)

FIG. 14

The Jolly balance used in this experiment consists of a spring attached at its upper end to a rod which may be raised or lowered so that an indicator may be brought to a given position of rest. The elongation is read by means of a scale and vernier. The whole system is supported on a base having three legs which are supplied with leveling screws.

Adjust the apparatus by means of the leveling screws so that the aluminum indicator is central in the glass tube.

Raise or lower the support carrying the upper end of the spring until the mark around the aluminum indicator is in the plane with the etched circle on the glass cylinder. Read the vernier.

Place the article to be weighed in the scale pan or suspend it from the hook. Raise the support until the line on the aluminum indicator coincided with the etched line on the glass as before. See that the indicator hangs free of the tube. Read the vernier.

The difference in vernier readings will give the elongation of the spring. If the elongation per gram is known the weight may be easily computed. If the elongation per gram is not known adjust the balance, read the vernier, add weights five

grams at a time until twenty grams have been added, taking vernier readings for each added weight. From these readings the spring constant may be computed.

Find the specific gravity of several liquids and a solid using the method outlined above.

Tabulate your readings carefully and show how computations were made. Indicate the numerical operations.

Experiment 25.

DETERMINATION OF THE ANGLE OF CONTACT OF MERCURY AND GLASS.

References: Watson, §§ 157, 159, 160.

In the case of a small tube the meniscus, or surface of liquid inclosed, is nearly spherical in form. That it cannot be *exactly* spherical follows from the fact that a liquid surface at rest is at every point normal to the resultant force, which in this case is composed of surface tension and gravity. For small tubes the error is negligible. Hence a thread of liquid inclosed in such a tube may be considered as consisting of a right cylinder capped at each end with a spherical segment of one base. If the radius r of this segment and its height h are known, the angle of contact α is known from the relation $h/r = \tan\frac{1}{2}(\alpha - 90^\circ)$. (To be proved by the student.)

Use three tubes and find the meniscus height of mercury and the radius in each as follows:

Introduce *clean* mercury into a *clean* glass tube, forming a short thread about one centimeter long near the middle of the tube. Fasten the tube horizontally with the clips or with wax, on the stage of a micrometer microscope. Focus the cross-hairs on the edge and then on the vertex of the meniscus, reading both scales of the instrument for each position. The dif-

ference of readings gives the meniscus height. Again fasten the tube in a vertical position, and measure its longest and shortest internal diameters at each end. From the mean of these four measurements find the radius.

Calculate the angle α in degrees and minutes.

Experiment 26.

SURFACE TENSION.

References: Watson, § § 156, 157, 159 and 160.

Surface tension may be measured in either of two ways: first by means of measuring directly the sustaining power of the film with some form of dynamometer; second by capillarity.

In this experiment it is to be measured by means of the Jolly balance, a spring dynamometer. (For a description of the Jolly balance see experiment No. 24).

A clean wire having a shape as indicated in the figure is suspended so that the longer part remains horizontal and a reading of the vernier of the balance is made.

FIG. 15

A beaker containing the liquid whose surface tension is desired is placed on the adjustable support of the balance and is raised until the horizontal portion of the wire is just submerged. Then no force due to surface tension is acting on the wire.

Now increase the tension on the spring very slowly, raising the wire out of the liquid until the film breaks. Read the vernier. The difference between the two readings multiplied by the constant of the balance will give the pull due to the surface tension in grams weight. If the constant of the spring is not given it may be determined by the method explained in experiment 24.

The maximum surface tension is then

$$T = \frac{kx}{2a} = \frac{m \text{ (grams } wt.)}{2a} = \frac{n \text{ dynes}}{2a},$$

where k is the constant of the spring, x is the elongation of the spring, and a is the length of the wire.

Make five trials on each liquid used.

Find the result in grams weight and in dynes.

Explain fully how the formula is obtained.

The aluminum wire and the liquid surface must be clean. Dip the wire in dilute sulphuric acid and agitate it a few moments, after which rinse first in distilled water, then in alcohol, and then dry it. Clean the wire after testing each liquid.

Experiment 27.

CAPILLARITY DETERMINATION AND SURFACE TENSION. USES OF THE CATHETOMETER.

References: Watson, §§ 20 and 160. Stewart and Gee, pp. 27, 35 and 284.

I. Adjustment of the Cathetometer.

In the instrument furnished the level is fastened to the telescope and it is assumed that the line of collimation of the latter is parallel to the former. Under one end of the telescope there will be found a screw by which the inclination of the telescope can be changed. Calling the foot-screws of the tripod P, Q, R, and the center of the same B as in Watson's figure, adjust as follows:

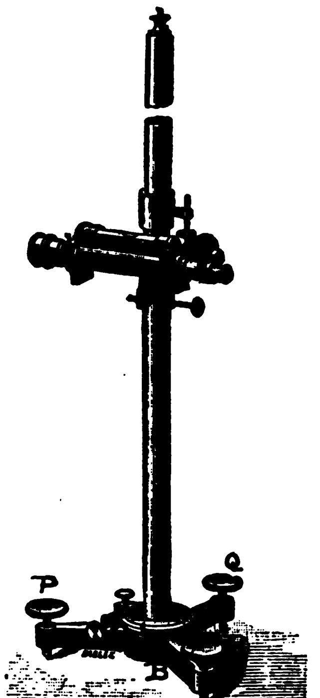


FIG. 16

(1) To adjust the cross-hairs to the focal plane, pull out or push in the eye-piece until the cross-hairs are clearly seen. Place the telescope at the correct height on the pillar and point it toward the object desired; pull out or push in the mounting carrying the eye-piece and cross-hairs until the object is clearly seen and the cross-hairs and object apparently have no relative motion when the eye is moved sidewise.

(2) To make the pillar vertical and the telescope horizontal, turn the telescope parallel to the foot-screws P, Q, level the telescope by means of the tele-

scope-screw beneath it, then turn the telescope 180°. If the bubble changes position, bring it back half with the telescope-screw, half with the foot-screws P, Q. Turn the telescope through a right angle, make it level with the foot-screw R. Repeat these steps, then test adjustments (1), if they have to be changed repeat both (2) and then (1) until all are perfect.

II. To determine the Surface Tension of Water.

Formula, $T = \frac{1}{2} h \rho r g$, since $\alpha = 0$ and $\cos \alpha = 1$.

Use a *clean* glass tube, supported vertically over a glass cell with plane sides ; pour in *clean* water to fill the cell 2 or 3 cm.

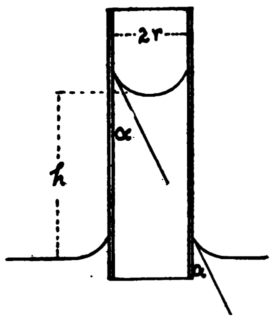


FIG. 17

above the bottom of the tube, and wait 2 min. or more, until the water has risen as high as it will go ; raise the tube about 1 cm. this insures that the inner surface of the tube be wet above the level of the water column in it.

Set the cross-hairs of the cathetometer on the lower edge of the meniscus, and read the vernier ; then on the level of the water in the cell, and read the vernier ; do this 3 times. The mean difference in the readings is h. Use three tubes of different calibers.

Take the temperature of the water. From tables find its density. Be careful not to touch the tube or the water with the fingers or to soil them in any way.

Measure the diameter of the tube with a reading microscope, as in Expt. 26, and find r. If the tube is not cylindrical assume that it has a uniform taper, and find the radius at the point where the meniscus stood by computation.

Compute T for each tube used.

As a correction to the height of the column, due to the fact that the water in the meniscus has not been taken account of above, ⅓ the radius of the tube may be added to the measured value of h.

Experiment 28.

ELASTICITY.

YOUNG'S MODULUS.

TENSION.

References: Watson, §§ 170, 171, 172 and 176.

Young's Modulus is defined as the force per unit cross section necessary to increase unit length of a substance by unit amount, provided the elastic limit of the substance be not reached. In most cases such increase is absolutely impossible, a very small increase in length only being possible within the elastic limit. Within the limits of this experiment we may assume that the increase of length is proportional to the force applied.

From the above definition it follows that $M = \dfrac{\frac{F}{q}}{\frac{e}{l}} = \dfrac{Fl}{qe}$

Where F is the force; q is the cross-section; e the elongation; and L the total length of the wire from the support to the mark where the elongation is measured, expressed in proper units.

One end of the wire is fixed. A mark near the other end is to be used as a reference point. The stretching force is to be applied to the free end of the wire.

Focus the cross-wire of a micrometer microscope on the mark

near the free end of the wire and read its position when enough force is applied to take the kinks out of the wire. Add a force equal to a kilogram's weight to the force acting and read again. Proceed in like manner until at least five elongations have been determined.

Reduce the force acting stepwise to the original value taking readings as a check on the original observations. If there be much discrepancy in the elongations repeat all the readings.

Determine the pitch of the micrometer screw.

Find the diameter of the wire used by means of the micrommeter gauge. Make determinations on different wires.

Define "elastic limit," "permanent set."

Arrange data as follows:

Material of wire.

Length of wire used=.

Diameter of wire=

Cross-section of wire=

Zero reading of instrument=

Pitch of micrometer= turns per cm.

Force producing elongation F.	Microscope reading.	Elongation e.	Modulus in grams wt.	Modulus in dynes.

Plot a curve using total elongations as ys and total Fs as xs. What does the curve indicate?

50,000 ohms.

Experiment 29.

YOUNG'S MODULUS.

FLEXURE.

Reference : Watson, §§ 171 and 173.

The bars to be tested are rectangular in cross-section. They are to be supported on two knife edges *a a* with a knife edge *c* supporting the weights used to deflect them. The experiment is to be performed as follows. Shift the knife edges used as rests to points near the ends of the base and equal distances from the center of the base.

Pass the bar to be tested through the U carrying the central

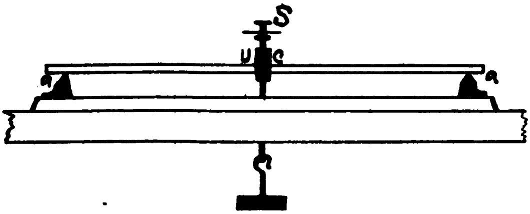


FIG. 18

knife edge. Shift the bar until the rod connected to the U passes centrally through the hole in the base. The axis of the bar should be at right angles to the knife edges.

Adjust the micrometer screw so that its axis is central over the knife edge supporting the weight.

Suspend 1 Kg. from the central knife edge and make a reading on the micrometer. Add a known mass to increase the deflection and read the micrometer. If the deflection is less than a complete turn of the micrometer screw add a greater mass. In like manner make five readings on the deflection of the bar.

Do not take any weights off until the micrometer has been raised two or three centimeters.

Make two sets of readings on the bar using different values of distances between knife edges.

Make two sets of readings, using bars of the same thickness but of different widths. Use the same distance between knife edges as in the first series of readings on the first bar.

Make a series of readings on bars having the same width but with various depths.

In making the adjustments the contact of the micrometer screw with the central knife edge will be indicated by a deflection of a galvanometer in circuit with a cell, the micrometer and the bar. The circuit will be open except when the bar and micrometer are in electrical contact.

Determine the width and thickness of the bars used with a micrometer caliper.

For a bar supported at two points with the deflecting force applied midway between them

$$l = \frac{PL^3}{4Ybd^3}$$

where l is the deflection due to a force P, L is the length between knife edges, b is the width of the bar, d its depth, and Y is Young's Modulus.

Arrange data as follows : Material of bars.

$L=$ cm., $b=$ cm., $d=$ cm.

Micrometer zero= Pitch of micrometer screw= turns per cm.

$$Y = \frac{PL^3}{4lbd^3}$$

P in Kg. Wt.	Micrometer Readings.	l in cm.

Plot one curve using values of P as abscissas and corresponding values of l as ordinates.

Plot one curve using values of ~~D^2~~ L^3 as abscissas and corresponding values of l as ordinates.

Plot one curve using values of $\frac{1}{b}$ as abscissas and corresponding values of l as ordinates.

Plot one curve using values of $\frac{1}{d^3}$ as abscissas and corresponding values of l as ordinates.

What do the curves and data show?

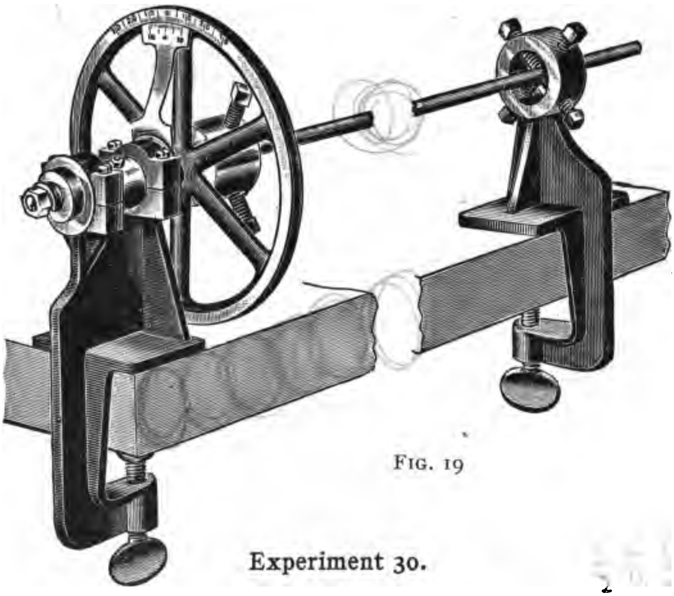


FIG. 19

Experiment 30.

TORSIONAL RIGIDITY.

References: Watson, §§ 171, 174, 175 and 176.

If a torque acts on one end of a wire the other end remaining fixed, an element originally parallel with the axis of the wire will be twisted into the form of a spiral, any radius being turned through an angle the value of which depends on the material of the wire or rod, its radius r, the distance l from the

fixed end to the radius in question, and the torque acting T, such that $\Phi=\frac{2lT}{\pi r^4 n}$ where Φ is the angle turned through in radians and n is a constant depending on the material of which the rod is composed.

If rods are square in cross-section use the following formula :

$$\Phi=\frac{6lT}{0.841 b^4 n} \quad \text{(Church's Mechanics.)}$$

The experiment consists in finding the constant n.

Clamp one end of the rod fast in the jaws that are fixed and the other end in the movable jaws. Be careful not to set the jaws so tightly as to jam the threads. The movable jaws are rigidly fixed to a wheel graduated in degrees. Around a groove in the wheel runs a cord to which is attached a pan in which weights may be placed. A movable vernier may be set at any desired division on the scale.

Set the vernier so that it reads about zero with no weights in the pan.

Read the vernier to tenths of a degree.

Place enough weights in the pan to turn the wheel through several degrees. Read the vernier.

Increase the weight in the pan by known amounts making the corresponding vernier readings.

Measure the radius of the wheel, the radius of the rod, and the distance between the free and fixed ends of the rod.

Set the fixed jaws at three other places along the bar and repeat the readings enumerated above.

For each set of readings compute values for n.

Repeat the experiment with two or more rods of the same material but of different diameters using the same lengths as in case one.

Tabulate your data.

Draw curves as follows :

(1) For constant values of T draw one curve using values of l as abscissas and corresponding values of Φ as ordinates.

(2) For constant values of T plot a curve using values of $1r_4$ and corresponding values of Φ for coördinates.

(3) For constant values of l, draw one curve using T torques as abscissas and corresponding values of Φ as ordinates.

What conclusions may be drawn from the curves and the results?

PART II.

HEAT.

Experiment 32.

CALIBRATION OF THERMOMETERS.

References : Watson, § § 179, 180 and 182.

In the experiments in heat one of the first requisites is to know the corrections for the thermometers used and to be able to reduce the readings taken on any thermometer used to that of one particular thermometer, which is to be used as a standard of reference.

Determine the zero point correction on two thermometers, and the boiling point correction on the third.

To determine the zero point correction pack the bulbs in melting snow or finely cracked ice that is at the melting point. Allow the thermometers to stand in the zero bath for 5 minutes before reading.

To determine the boiling point correction the thermometer is placed in a steam bath that envelopes the bulb and stem up to a point very near the boiling point. No part of the thermometer must be in the boiling water. The steam should be allowed to escape freely from the apparatus so (See figure 144 Watson's Physics) that the atmospheric pressure under which the water boils may be known.

Since the boiling point changes with the pressure at which boiling takes place, read the barometer. For the boiling point at the particular barometric pressure consult tables or get it from curves drawn for that purpose.

Allow the thermometer to remain in the steam bath for at least five minutes before reading.

Find the reading of the thermometer also when most of the

stem is exposed to the air, the bulb and a very small portion of the stem being in the steam bath. This will give the stem correction for one or two experiments to follow, at ordinary room temperatures.

Thermometers.

S	1	2
0.0	0.00	-0.08
2.0	2.03	1.95
3.5	3.53	3.40
6.0	6.05	5.80
8.0	8.04	7.80
10.0	10.00	9.90
12.0	11.94	12.00
14.0	13.95	14.12
16.0	15.96	16.06
18.0	17.96	18.00

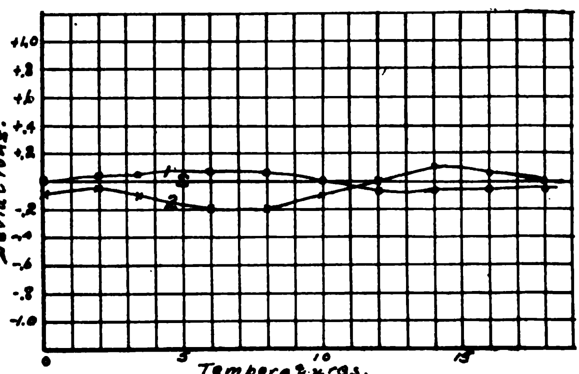


FIG. 20

The thermometers are now to be calibrated or standardized so readings on any one may be referred to any other thermometer taken as a standard of reference.

The Calibration of Thermometers is to be made as follows:

Place the thermometers in the calorimeter with some water at 5°C. or 6°C. taking care that the bulbs are completely covered. Read the thermometers as quickly as possible in all observations for they are generally constantly changing. Pour in warm water sufficient to raise the temperature of the thermometer 6 or 8 degrees and quickly read all thermometers again. Continue this process until a temperature of about 50° has been reached. Assume one of the thermometers as a standard and plot curves of corrections for the other thermometers, from which the corrected reading in the experimental work may be determined. See readings and curve in Fig. 20.

Experiment 34.

CO-EFFICIENT OF EXPANSION OF AIR AT CONSTANT PRESSURE.

References: Watson, § §, 193, and 194.

A glass tube of small bore is closed at one end and has a drop of mercury about half way between the open end and closed end. The tube is placed in a horizontal position in an ice water bath with the open end above the surface of the water. To secure this there should be a bend in the tube not far from the open end.

When the temperature of the bath and hence the air in the tube is at 0°C, measure carefully the distance of the drop of mercury from the closed end of the tube. Assuming the section of the tube to be uniform, this length is proportional to the volume of the air enclosed in the tube by the drop of mercury. Raise the temperature of the bath successively to 25°, 50°, 75°, and the boiling point, and in each case measure the volume of the air enclosed in the tube. This measurement should be especially careful at the freezing and boiling points.

Tabulate data and results as below :

Length of air column proportional to volume.	Temperature of enclosed air.	Pressure of enclosed air.

Plot a curve with temperatures as abscissas and volumes as ordinates. Draw conclusion. Prolong this curve to the left of the origin and determine at what temperature below zero the volume of air would become zero, *if change in volume were to continue at the same rate.* Compute the coefficient of expansion of air at constant pressure.

Experiment 35.

Measurement of the Coefficient of Linear Expansion of Metals.

References : Watson, §§ 184 and 185.

The coefficient of linear expansion of a metal may be defined as the increase in length per unit length of a metal, per degree of rise of temperature.

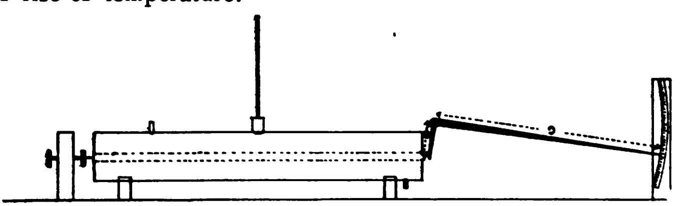


FIG. 21

The coefficient may be different at different temperatures. Frequently a mean temperature coefficient is found between two standard temperatures, for example, between the temperatures of 0°C. and 100°C.

If α is the temperature coefficient of a metal and l_0 is its

length at $0°C.$ then the length l at any other temperature $t°$ will be

$$l = l_0 (1 + at°).$$

In finding the temperature coefficient in this experiment the limits of temperature used will be between $100°C.$ and some much lower temperature as near $0°C.$ as practical.

The coefficient is to be computed from the measured increase in length of a given rod due to a known rise in temperature.

As the increase in length is very small a magnifying device must be made use of.

AB (Fig. 21) is the rod inside of a steam jacket. One end of the rod rests against a fixed support, the other end is in contact with the short arm of a right angled lever. The axis above which the lever rotates is at *P*. The long arm moves freely in front of a scale at *S*.

Measure the length of the rod and each arm of the right angled lever, using especial care in measuring the short arm. Fill the steam jacket with cold water, insert the thermometer and observe the temperature. Observe with great care, estimating to tenths of millimeters, the position of the long arm of the lever. Use the mirror to avoid parallax. Remove the water from the steam jacket, and send steam through the latter until the temperature within ceases to rise. Again observe the temperature and note the position of the long arm of the lever.

Tabulate data as follows :

Metal,
Length of rod =
Length of long lever arm, c, =
Length of short lever arm, e, =
Lower temperature of rod =
Higher " " =
Position of long arm at lower temperature =
Position " " higher " =
Increase in length of rod =

Rise in temperature =
Coefficient of expansion, α, =

NOTES ON CALORIMETRY.

References: Watson, §§ 182 and 199.

The general principle to be applied in all calorimetric work is the equivalence of the loss and gain of heat by the two components into which a system may be divided. As an example suppose a copper vessel be partially filled with cold water at a certain temperature then a definite amount of warm water is added. Provided there are no heat losses, such as radiation or conduction from the system, the heat lost by the warm water will be exactly equal to the heat gained by the cold water and the copper calorimeter. Thin copper vessels are used on account of their good conducting power, which ensures the temperature of the calorimeter to be very nearly that of its contents, when the contents are well stirred. In calorimetric work there are very many chances for errors and great care must be used to reduce these to a minimum.

Among the losses to be guarded against are those due to *radiation* or *absorption*. In the present work these losses will be neglected; not that they are very small, but that a proper correction involves more work than we have time for. These losses are reduced to a minimum however by trying to have the calorimeter surface above and below room temperature by equal amounts for equal times, so choosing temperatures and masses that the final temperatures will be as nearly as possible that of the room.

Conduction losses will be reduced to a minimum by using insulating supports, such as glass, for the calorimeter.

The water equivalent of the calorimeter must be always taken into account. The calorimeter changes through the same range of temperature as its contents and takes up or gives out a certain amount of heat in doing so. That mass of water that takes

up or gives out the same amount of heat when changed through the same range of temperatures as the calorimeter, is called the water equivalent of the catorimeter.

The thermometers used in calorimetric work may require the results to be corrected for their water equivalent and also on account of inaccuracy of scales. The readings of the thermometers in the experiments in heat must be reduced to the reading of one particular thermometer which is to be assumed a standard

Experiment 37.

DETERMINATION OF THE WATER EQUIVALENT OF A COPPER CALORIMETER AND THE SPECIFIC HEAT OF COPPER.

References: Watson, §§ 199–201.

A calorimeter takes up or gives out heat when changing in temperature. The number of calories of heat taken up or given out by the calorimeter when changed through one degree is called its water equivalent.

To find the *water equivalent.*

Weigh the calorimeter with its stirrer.

Fill the calorimeter about ⅔ full of water about 5° below room temperature and weigh carefully. Heat some water to about 10° above room temperature in another vessel. Stir the water in each vessel thoroughly and read the temperatures of each caretully. Pour enough of the hot water into the calorimeter to nearly fill it. Read the temperature of the resultant mixture every 15 or 20 seconds until it reaches a steady value. This usually takes not more than 2 minutes. Be very careful in reading temperatures and in making weighings. Make at least two runs. Show the results to an instructor before proceeding.

From the determined water equivalent and the mass of the calorimeter, find the specific heat of copper.

Experiment 38.

Determination of the Specific Heat of Metals.

References: Watson, §§ 200 and 201.

The specific heat of a substance may be defined as the amount of heat, in calories, necessary to raise the temperature of one gram of the substance one degree. The specific heat of a substance may be different at different temperatures, and in different states. For example ice has a specific heat different from that of water or steam.

The specific heats of metals are to be found, in this experiment, by the method of mixtures, in one of the ways outlined below.

(1) If the metal is in a finely divided form as in shot or bits of wire determine the mass of the metal. Put it into a cup made to fit into a metal boiler. Pass a thermometer through the cork cover of the cup. The metal should completely surround the bulb of the thermometer.

Heat the water in the boiler until the thermometer readings do not change. This will probably occur within five minutes after the water has begun to boil.

Quickly remove the thermometer and cork from the cup and pour the metal into a calorimeter two thirds full of water at a measured temperature of about ten degrees below the room temperature. Insert a thermometer through a hole in the cover of the calorimeter and take temperature readings every thirty seconds until the temperature becomes constant, stirring the water vigorously all the time.

Weigh the mixture.

Knowing the mass of the calorimeter, the metal whose specific heat is to be determined, and the mixture, and also the temperature of the metal and cold water just before mixing, the final temperature of the mixture, and the water equivalent of the calorimeter, the specific heat may be determined.

If the water equivalent has not been previously determined or given, it may be found by multiplying the mass of the copper calorimeter by the specific heat of copper.

Make two determinations of the specific heat of the given metal.

(2) If the metal of which the specific heat is to be determined is in a lump the following method is to be applied.

Suspend the metal whose mass has be n previously determined in a calorimeter about two thirds full of water six or eight degrees below room temperature. The mass of the water must be known as well as the mass of the metal.

Heat some water in another vessel to a temperature of ten or fifteen degrees above room temperature. Stir the water in both vessels thoroughly and read the temperatures of both masses of water. Immediately after having determined the temperatures, pour the hot water into the calorimeter containing the metal until it is nearly full.

Stir the mixture vigorously and take thermometer readings until the mixture comes to a constant temperature. Find the mass of the mixture.

From the temperatures of the hot and cold water just before mixing, the final temperature of the mixture, the mass of the metal, cold water, hot water added, and the water equivalent of the calorimeter the specific heat may be determined.

Make two independent determinations of the specific heat.

Experiment 39.

DETERMINATION OF THE HEAT OF FUSION OF ICE.

References: Watson, § 211.

The heat of fusion of a substance is the amount of heat required to change a gram of the substance from a solid to a liquid state without any perceptible change in temperature. The

object of this experiment is to find the heat of fusion of ice, using the method of mixtures.

Determine the mass of a calorimeter and stirrer. Assume the specific heat of copper as 0.093 and compute the water equivalent of the calorimeter.

Into the calorimeter about three-fourths full of water, at a temperature of about 5° above the room temperature, place a piece of ice about the size of a 500 gram wt. The mass of the water and its initial temperature should have been determined just before adding the ice. Stir the mixture thoroughly making readings every 15 seconds during the drop of temperature, or until the temperature of the mixture begins to rise. All the ice is then melted. The lowest temperature is to be taken as the temperature of the mixture. Weigh the mixture to find the amount of ice used.

The ice should be allowed to stand in the room for some time before using to be sure that it is at 0°C. It should be dried by rolling in filter paper befoie putting it into the calorimeter.

Use glass supports to reduce conduction to a minimum. How is radiation reduced to a minimum?

In making computations make use of the principle that the heat lost by one part of the system is equal to that gained by the other part.

Make two independent determinations.

Experiment 40.

Determination of the Heat of Vaporization of Water.

References: Watson, §§ 213–215.

Many substances in the liquid state have their temperatures raised when heat is applied until they reach certain temperatures, depending on the substance and pressure applied, at which evaporation takes place. Provided the pressure be not changed the evaporation continues at a constant temperature until the whole mass is vaporized. In many cases a large amount of

heat is required for this change, as in the case of water, it requires a large number of calories to change a gram of water from a liquid to a vapor at a temperature of 100°C. under a pressure of 76 cm. of Hg.

The object of this experiment is to make determinations of the heat of vaporization of water. The method to be used is the method of mixtures. Run the steam generator for a few minutes, until the issuing steam is as dry as possible, then insert the end of the steam tube into the calorimeter through the cover. The calorimeter should be about ¾ full of water at a temperature about 5° or 10° below room temperature. The mass of the calorimeter and cold water should have been previously carefully weighed. The water should be thoroughly stirred and its temperature carefully determined just before inserting the steam tube. Take reading of the resulting mixture every 15 seconds until its temperature is about as far above room temperature as it was originally below that temperature. Then take out the steam tube. The stirring, which should be kept up all the time the steam is condensing, should be continued until the temperature of the mixture begins to drop. The highest temperature attained is to be taken as the temperature of the mixture. Radiation losses are reduced to small values by the above process. (Why?) Conduction is guarded against as much as possible by keeping the calorimeter on glass supports. Weigh the resultant mass to find the mass of the steam condensed. Apply the principle of the loss of heat by one part of the system being equal to the gain by the other part of the system, and determine the heat of vaporization.

Read the barometer and determine the boiling point of water for the particular pressure from tables or a boiling point-pressure curve.

Determine the water equivalent of the calorimeter and stirrer from their mass and the specific heat of copper. Assume the specific heat of copper as 0.093.

Make two separate determinations of the heat of vaporization.

PART III.

EXPERIMENTS IN WAVE MOTION AND SOUND.

Experiment 50.

WAVE MOTION. STATIONARY WAVES.

References: Watson, §§ 266, 267, 275, 276.

Read carefully the above references and perform the following experimental work:

With vertically suspended rope.

Hang a mass of one kilogram on the lower end of the rope. Strike the rope a blow and note the progress of the wave along the rope. At the upper fixed end reflection will take place with "change of phase" Note the progress of the return wave and the position of the crest of the wave relative to the vertical line from the point of suspension, with relation to the crest of the incident wave. Repeat several times; then add one kilogram and try again noting the change in the velocity of the wave along the rope.

Take off the weights at the lower end of the rope and from the upper end of the rope send waves down the rope and note carefully the reflection from the "open" end. The reflection in this case is "without change of phase."

Stationary waves. (Transverse.) Suspend 1 kg. at the lower end of the rope. Grasp the rope near the lower end firmly, but in such a manner that the tension in the rope may not be affected. Cause the rope to vibrate in one segment and count the number of vibrations in half a minute. Then cause the rope to vibrate in two segments and find the number of vibrations in thirty seconds. Finally cause the rope to vibrate in three seg-

ments and get the corresponding number of vibrations in half a minute. Put all data in your note book.

Increase the tension in the rope by adding 1 kg. and repeat the above observations. Then increase the tension to that produced by 3 kg. and make observations as before.

When the rope is vibrating in one segment the distance from the upper fixed end to the fingers corresponds to nearly a half wave length; when vibrating in two segments the distance corresponds to a whole wave length; and when vibrating in three segments it corresponds to one and a half wave lengths.

Since in the formula $v=\lambda f$, where v is the velocity of propogation, λ the wave length, and f the frequency; v is constant, show the relation between λ and f in any set of observations.

In paragraphs 275 and 276 (Watson's Physics) it is shown that $v=\sqrt{\frac{T}{m}}$; that is, that v varies with the square root of the tension. Verify this from the data taken.

Take the suspended mass off and from the upper end of the the rope produce stationary waves having one, two and three nodes between the upper and lower ends, note carefully the positions of the nodes in each case. What portions of a wave length does the rope vibrate in, in each case?

Stationary Waves, Longitudinal.

A coil of wire is suspended with its axis horizontal. With both ends of the coil free to vibrate. strike one end a light blow and note the progress of the wave. The reflection of the wave will be at an "open" end and therefore "without change of phase." By striking one end at the proper intervals produce stationary waves, first with one node between the ends, then with two nodes and finally with three nodes between the ends. In each case count the number of vibrations in 1.5 seconds, repeating the observations at least three times. Note the relation between the length of the coil and the wave length; also between the wave lengths and frequencies.

Repeat the above observations with one end of the coil fixed. In all cases be sure that the vibrations are not forced.

Show diagramatically the production of the stationary waves when using the coil for both cases ; first with both ends free ; second, with one end fixed, or a node.

Experiment 51.

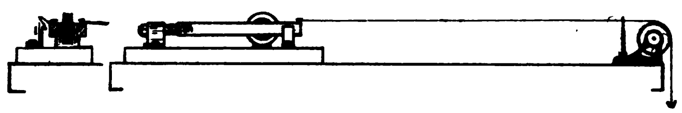
STUDY OF VIBRATING STRINGS. MELDE'S EXPERIMENT.

References : Watson, § § 297–298, Experiment 50.

The theory necessary to an understanding of the following experiment should be fully understood before performing any of the experimental work.

I.

Mount a tuning fork so that its prongs vibrate at right angles to the axis of a light strong horizontal cord, one end of which is attached to one prong of the tuning fork. (See figure 22*a*.) The cord passes over a bridge and a pulley near the other end.



(b). (a).

FIG. 22

At the end is attached a pan of known mass for holding weights by means of which the tension in the cord may be varied. The required tension may be obtained by using a carefully calibrated spring with an adjustable end.

Adjust the tension of the string until it breaks up into vibrating segments in unison with the vibrating fork. Make a note of the mass used and the length of the vibrating segments.

Vary the tension until the string breaks up into a different number of vibrating segments. Observe and make a note of

the mass and length of the vibrating segments between nodes as before. Make a third set of observations.

Find the mass of the cord per unit length and from the data obtained compute the frequency of the cord and fork from the expression.

$$N=\frac{1}{\lambda}\sqrt{\frac{T}{m}}=\frac{n}{2l}\sqrt{\frac{T}{m}}$$

Where T is the tension, m the mass per unit length, λ the wave-length, N the frequency, l the distance between any two nodes, and n the corresponding mumber of vibrating segments.

II

Mount the fork so that the direction of vibration of the prongs is parallel with the axis of the cord. (See figure 22*b*.) Cause the fork to vibrate and change the tension of the cord until it vibrates forming nodes and vibrating segments. Note the mass and lengths of vibrating segments as before. Make three sets of observations using different masses.

Knowing T, m, and l compute N as before. N is in this case the frequency of the string. Find the frequency of the fork.

Tabulate data carefully.

Experiment 52.

DETERMINATION OF THE FREQUENCY OF A TUNING FORK BY MEANS OF A VIBRATING STRING.

References: Watson, § 297.

A stretched vibrating string may vibrate transversely with the ends of the strings as nodes and the intermediate portion for the vibrating segment. When this is the case the string is giving out the lowest tone it is capable of, for the given tension and length.

This tone is called the fundamental. For a given string the

frequency of vibration will vary with the tension and length of string. A stationary wave train is set up of which the velocity is equal to the square root of the tension divided by the mass per unit length.

$$v = \sqrt{\frac{T}{m}}$$

The velocity of the wave is equal to the frequency times the wave length, $v = n\lambda$.

The fundamental wave length of the transverse wave is equal to twice the distance between the nodes.

Therefore $v = 2\ nl$

From which $n = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{\lambda}\sqrt{\frac{T}{m}}$

I.

Adjust the length of a given string for a given tension until the string vibrates in unison with a fork of known frequency.

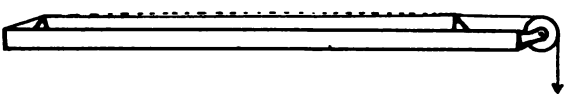


FIG. 23

Find the mass of a known length of a sample of wire like the given string, from which compute the mass per unit length.

Measure the length of the vibrating segment in centimeters for a given tension in dynes. Make three settings of the bridge for each tension in order to get a good average.

Keeping the tension constant adjust the length of the string until it is in unison with two other forks, noting the corresponding lengths.

Compute the value of n from the data obtained by the formula and compare the result with the known frequency of the fork.

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{\lambda}\sqrt{\frac{T}{m}}$$

II.

Keeping the length of the string constant change the tension until unison is obtained with each of the three forks, repeating observations two or three times as a check.

Compute the values of n and compare with the known values of the frequencies of the forks.

Arrange data as follows :

Station.	Mass of a given length.	$m/cm.$	Length in cm.	Mass on wire.	Tension in dynes.	$n.$

From the formula it will be noted that, for a constant tension the frequency varies inversely as the length, and for a constant length the square of the frequency varies directly with the tension.

Draw two curves, using suitable scales, to verify the above. Plot a curve for part I using values of the reciprocal of the string lengths for abscissas and corresponding frequencies for ordinates. For part II plot a curve using tension in kg. wt. for abscissas and corresponding values of frequencies squared for ordinates.

Experiment 53.

DETERMINATION OF THE VELOCITY OF SOUND IF AIR.

RESONANCE TUBES.

References : Watson, §§ 306, 307, 313.

Read carefully the paragraphs in Watson's Physics above referred to for the fundamental theory.

If a vibrating tuning fork be placed near one end of a tube containing a gas, sound waves will be transmitted through the tube by the gas at a definite rate depending on the nature of the gas and its temperature.

Reflection will take place from the other end of the tube, "without change of phase" for an open end, and "with change of phase" for a closed end. If the tube be of the proper length a stationary wave train is produced and the tube resounds to the fork. If the tube be closed at one end, or if a movable

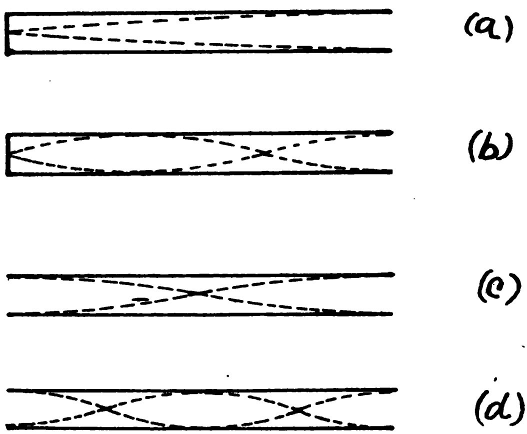


FIG. 24

piston be placed in the tube from which the reflection may take place, it may be possible to find several positions of the piston for which resonance will take place. The shortest length of tube for which resonance takes place will be such that the time taken for the sound wave to go from the open end to the closed end and back again will be equal to the time it takes the fork to make a half vibration. Therefore the length of the vibrating gas column will be one fourth the wave length of the sound in the given gas. (Fig. 24 a). The next longest resonating

length will be three fourths of a wave length (Fig. 24 b), and so on.

Since the velocity of sound is equal to the wave length times the frequency, the following expression for the velocity in terms of the vibrating tube length may be derived.

$l=\frac{n\lambda}{4}$ where n is odd, and $v=N\lambda$ from which $v=N\frac{4l}{n}$.

For a tube open at both ends, since loops or vibrating segments must be situated at the ends,

$l=\frac{n\lambda}{2}$ where n is any whole number. For open tubes, therefore, $v=N\frac{2l}{n}$. See figures 24 c and 24 d.

Use a tube having a movable piston and find several points of resonance for two forks of different periods, making several settings for each point of resonance.

Owing to the sound waves spreading out in the tube the measured lengths are not quite accurate, but must have a correction added to the readings. This correction is very nearly equal to .6 of the radius of the tube. The difference in the length for two adjacent settings is quite accurately equal to $\frac{1}{2}\lambda$.

Observe if the tube will resound to either fork when the piston is removed.

Reduce the velocities obtained to O°C. using the formula $v_t=v_0\sqrt{(1+0.00367t)}$.

Show by diagrams how the air column breaks up. Arrange data as follows:

Frequency of fork= Radius of tube=
Temperature= Correction added=

$l_1+.6r=\frac{\lambda}{4}$	v_1	$l_2+.6r=\frac{3}{4}\lambda$	v_2	$l_2-l_1=\frac{\lambda}{2}$	v_3

Mean velocity=
Velocity at O°C.=

Experiment 54.

VELOCITY OF SOUND IN SOLIDS. KUNDT'S EXPERIMENT.

References: Watson, § § 312–314. Experiment 53.

Rods made of elastic substances are capable of vibrating both transversely and longitudinally. This experiment is intended as a means of determining the velocity of sound in metal or glass rods along their length. The experiment depends on the resonance of a column of air or some other gas or gases in which the velocity of sound is known. It may also be used to find the velocity of sound in a gas by comparison.

A rod of the substance to be studied is clamped at its middle (Fig. 25). Longitudinal vibrations are excited in the rod by stroking it with a piece of leather covered with rosin if metal, or

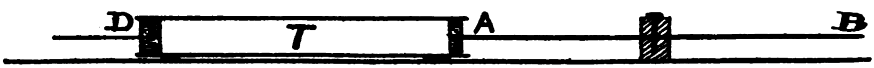


FIG. 25

with a wet cloth if the tube is glass, in the direction of the axis at the end *B*. A piston on the other end of the rod fits into the tube *T* at *A* snugly without binding. At the end of the tube *D* is a movable close fitting piston. The tube *T*, which must be dry, contains some lycopodium powder or cork dust along its lower side.

When the rod is in vibration the vibrations are transmitted to the air in the tube by the piston *A*. The piston *D* is adjusted until the tube is of proper length for resonance. When resonance is obtained the powder or cork dust will be collected at the nodes. There will be a node at the movable piston *D* and one near the movable piston *A* attached to the rod. The piston *A* will be at some point in the vibrating segment.

Excite the rod and adjust the piston *D* until resonance is obtained. Measure the distance between the nodes most widely

separated. Count the number of segments. Compute the wave length of the sound in air, remembering that the distance from one node to the next is half a wave length. Note the temperature of the air and assuming the velocity of sound in air at 0° C. is 332 meters per second find the velocity of sound in the tube. From the results obtained compute the frequency of the sound.

Since the rod is free at both ends and fixed at its center it vibrates like an open organ pipe sounding its fundamental. From this fact and the computed frequency find the velocity of the sound in the rod.

Disturb the powder in the tube, change the position of the piston *A* with respect to the tube and make two or three more trials.

Arrange data systematically and show how computations were made.

Experiment 55.

A STUDY OF BEATS AND INTERFERENCE OF SOUND.

Reference : Watson, § 316.

Two tuning forks of very nearly the same frequency, mounted on their resonance boxes are used in the following experiments. The frequency of one fork is given.

I.

Remove one of the forks from its box and cause it to vibrate. Hold it by the stem in front of a tube adjusted to resonance (See experiment 53) and rotate the fork slowly about its own axis. It will be found that for certain positions of the fork the resonance is a minimum. Explain why this is so.

The same phenomenon may be observed if the fork is caused to vibrate and is held by the stem, prongs downward, and slowly revolved about its axis, near the ear.

II.

Mount the forks on their respective resonating boxes, and set both in vibration. Determine the number of beats per second; and having given the number of single vibrations of the known fork per second, compute the corresponding number for X from the frequency of beats.

III.

(1) Stick a small lump of wax on each prong of one of the forks and note the effect on the beats. (2) Adjust the wax weights so as to make the forks in unison. On which fork must the wax be placed? Why? (3) Observe the effect when the wax is removed from the one weighted to give unison, and large lumps are placed on each prong of the other fork.

If the experiment is carefully worked through and thought out in detail, the written report may be made very brief as suggested in the following outline.

OUTLINE OF RESULTS OF EXPERIMENT.

I. Minimum sound in ...... positions. Diagrams.*
" " due to..........
Waves reach ear in ...... phase. Why?

II. Frequency of beats........
C marked........single vibrations per sec.
X makes........ " " "

III. (1) Period of beats......(increased or decreased).
(2) Wax on fork . ...Why?
Pitch of...... (raised or lowered).
(3) Tones differ by .....half steps (approximate number).
Effects on ear, how changed?

*Relative positions may be represented by points, two for prongs, and one for ear.

Experiment 56.

DETERMINATION OF THE FREQUENCY OF A TUNING FORK.

References: Watson, § 300.

Tory & Pitcher, Experiment 7.

In this experiment the periodic time is compared with the periodic time of a short pendulum by causing both to make tracings simultaneously on a moving glass plate coated with "Bon Ami".

The fork is clamped in a holder so that it may vibrate in a horizontal plane with the ends of its prongs very near the short pendulum which is so mounted as to vibrate in a vertical plane. The glass plate is mounted on a carriage which enables the plate to be moved in a horizontal plane parallel with the plane of its face. A stylus attached to the pendulum and another attached to one prong of the fork are adjusted to bear lightly on the uncoated glass. Coat the glass with a smooth even layer of the Bon Ami, not too thick. Adjust the plate on the carriage so that when the pendulum and fork are vibrating and the carriage is moved, two sinuous lines will be traced on the surface of the glass.

Set the fork and pendulum vibrating and obtain curves. Get three sets of curves by repeating the process shifting the plate on the carriage sufficiently so that there is no overlapping.

The curves traced on the glass will be sine curves provided the motion of the plate is uniform.

The curves enable one to count the number of vibrations which the fork makes during one vibration of the pendulum. This can be done even if the plate were not moved with uniform speed although the curves will not then be true sine curves.

Determine the periodic time of the pendulum in the same manner as in experiment 17, taking the time of every tenth transit to the right from 1 to 91. This gives the equivalent of 250 vibrations.

In getting the corresponding number of vibrations of the two styli account must be taken of their distance apart in the direction of motion of the plate.

Tabulate data for the periodic time of the pendulum as in experiment 17.

Number of vibrations of pendulum in a given length.	Number of vibrations of the fork in the same length.	Ratio of vibration of fork to pendulum.

Period of pendulum= Period of fork, computed=
Frequency of pendulum= Frequency of fork, computed=
Marked frequency of fork=

PART IV.

EXPERIMENTS IN LIGHT.

Experiment 60.

PHOTOMETRY.

THE BUNSEN PHOTOMETER.

References: Watson, § § 358–361.

Nichols & Franklin, Vol. III, pp. 124–126.

The Bunsen photometer is to be used in the following described experiment to compare the brightness of different light sources and to study the distribution of the horizontal intensity from one or more light sources.

The fundamental principle of photometry (sometimes called Bouguer's Principle) is, that if two sources produce equal intensities of illumination at a given place their candle powers are directly proportional to the squares of their respective distances from the place.

$$B_1/B_2 = d_1^2/d_2^2$$

The apparatus to be used in this experiment comprises a photometer, a graduated photometer bar and two light sources, one of which may be assumed as a standard. The two standards in most common use are the Hefner lamp, burning amylacetate, and the standard sperm candle weighing six to the pound and burning 120 grains per hour. The ordinary parafine candle burns about 123½ grains or 8 grams per hour.

Directions for performing the experiment.

If a candle is used for a standard light source, it should be burned for a little time, until the wick is in good condition, then the flame extinguished and the candle weighed.

Place the two light sources on the photometer bar at 100 cm. distance from each other at the height of the photometer disk. Take frequent photometer reading for a half hour, being careful to displace the photometer after each reading, and then readjusting it until the disk is equally illuminated over its entire surface. On account of a difference in the color of the light sources this may be somewhat difficult. Do not throw out any readings because they seem wrong. If the light source tested has flat faces, as in the case of a common gas burner, place the plane of the flame at right angles to the bar and take fifteen or twenty readings; then turn the flame through an angle of 30° take fifteen or twenty more readings and so on until the flame has been turned through 180°. Do not let the gas flame blow.

At the end of the run extinguish the standard candle, noting the exact length of time it has been burning, and find its loss in weight. From this loss compute its candle power. From the known candle power of the standard source, and the average distances of the sources from the photometer disk for any position of the secondary source, compute the intensity of the second source for the different orientations.

Using polar coördinates, plot a curve showing the distribution of the light about the secondary source.

Original mass of candle = *g*.

Final mass of candle = *g*.

Whole time candle was burned= h. m. sec.

Computed candle power=

Distance between sources= cm.

Position of source (angle of plane of flame with bar).	Distance of standard from photometer, d_1.	Dist. of second source from photometer, d_2.	d_1^2/d_2^2.	I.
	Average.	Average.		

Experiment 61.

THE LAWS OF REFLECTION.

References: Watson, §§ 329–330.

This experiment is given to verify the laws of reflection. The apparatus necessary consists of the note book, a mirror capable of being mounted vertically and some pins.

The following directions will be found to be in accord with the discussion given in the references.

Mount a plane mirror vertically in wooden clips. Place it so that the face of the mirror lies along a line on a page of your

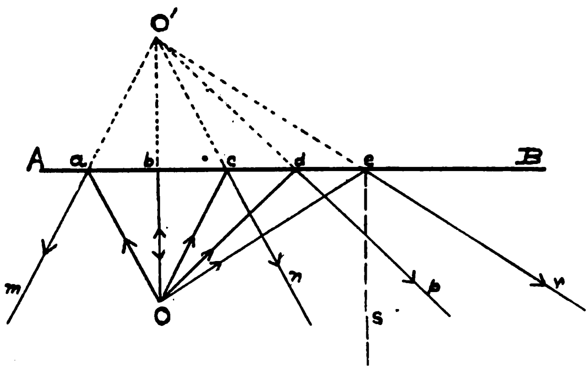


FIG. 26

note book. Stick a pin at *o* ten or fifteen centimeters from the mirror at *b*.

If there be no vertical markings on the mirror stick pins at points along its face about two or three centimeters apart as at *c*, *d*, *e*. . . . .

Mark the points *c*, *d*, *e*. . . . on the note book page.

Place the eye successively at such points that looking along the surface of the paper at the reflection of the pin at *o* in the mirror, it will appear to be behind the points *c*, *d*, *e*. . . . . Mark

points on the lines of sight with a pin point, as at *m*, *n*, *p*, *r*...

Remove the mirror, carefully marking its position.

Connect the points *ma*, *ne*, etc., by lines, producing them backward until they intersect. These points of intersection should be coincident if the conditions of the experiment be perfect.

Suppose o' be the point of intersection. Draw the line oo' cutting the mirror line at *b*.

Draw some line *es*, perpendicular to *AB*. Prove the angle of reflection equal to the angle of incidence.

Remember that all the images of *o* appear to be at o' but as o' is behind the mirror no real images exist. The images are also erect which is in accordance with the general law that all virtual images are erect.

Compare the distances from *o* to the mirror at the points *a*, *b*, *c*, *d*...with the distances from o' to the same points. Explain any peculiarities in the differences.

Distances from *o* to mirror at	Distances from o' to mirror at	Differences.
a	*a*	
b	*b*	
c	*c*	
d	*d*	
e	*e*	

Experiment 62.

DETERMINATION OF THE ANGLES OF A PRISM BY REFLECTION.

References : Watson, §§ 336. Experiment. 61.

The polished faces of a prism may be used as mirrors and by means of reflection from the surfaces the angles of the prism may be found as in the following experiment.

Place a prism with the intersecting edges of its rectangular faces vertical, on a blank page of the note book.

Trace the outline of the prism on the paper.

Place a pin O in front of the angle A to be measured. Observe the reflection of the pin O from each reflecting face, getting the reflected ray to come from as near the apex A as possible. Then set pins along the reflected rays, ten or fifteen centimeters from A as at e and f.

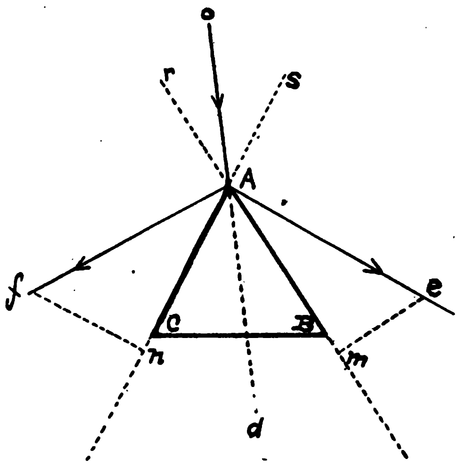


FIG. 27

Drop perpendiculars from the points e and f to the sides of the prism produced as at the points m and n.

$\angle fAn = \angle nAd$, and $\angle eAm = \angle mAd$. (Prove.)

But $\angle nAd + \angle mAd$ is equal to the required angle. Therefore the angle required is equal to $\angle fAn + \angle mAd$.

Measure off very carefully the lengths fA and fn, and also the lengths eA and em.

Then $\dfrac{fn}{fA} = \sin \angle fAn$, and $\dfrac{em}{eA} = \sin \angle eAm$.

From a table of natural sines find the angles fAn and eAm from which compute the required angle.

Find each angle of the prism.

Angle.	fn.	fA.	fn/fA.	$<fAn$.	em.	eA.	em/eA.	$<eAm$.	$<BAC$.
1									
2									
3									

The sum of the three angles=.
Difference of sum from 180°=.

Experiment 63.

Determination of the Index of Refraction of a Solid and a Liquid.

References: Watson, 341–342.

The theory of the experiment in outline is as follows:

A ray of light passing from a rarer to a denser medium is bent toward the normal to the surfaces of contact of the two media at the point of incidence. A ray passing from a denser to a rarer medium is bent from the normal.

If i be the angle of incidence and r be the angle of refraction for any two media the following relation is found to hold

$$\frac{\sin i}{\sin r} = \mu \qquad (1)$$

In the above expression is μ called the index of refraction for the two media used and is numerically equal to the ratio of the velocity of light in the two media.

Place a transparent plate with parallel sides on a page of the note book, about the center of the page.

Stick two pins vertically into the sheet at a distance of ten or fifteen centimeters apart so that the line joining them makes some angle between 30° and 60° with one edge of the plate.

On the opposite side of the plate adjust the line of sight until

the two pins are in line. Then mark out the line of sight with two other pins.

Draw the outline of the plate on the page and remove it.

Draw the lines *abo*, and *edc*, through the locations of the pins to the points of intersection with the outline of the plate at *o* and *c*.

Connect *o* and *c*. Erect a perpendicular to the edge of the plate at *o* producing it to intersect the opposite edge at *k*. Drop a perpendicular from *o* to the line *e d c* produced at *h*. Drop a perpendicular from *a* to some point *f* on the line *k o f*.

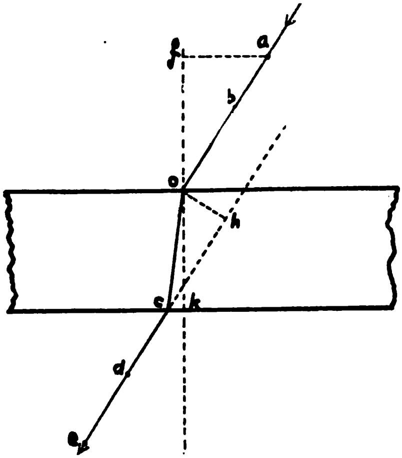


FIG. 28

Then $\frac{af}{ao} = \sin \angle aof = \sin i$

and $\frac{ck}{co} = \sin \angle cok = \sin r$,

from which find μ using equation (1).

Repeat the above experiment for two other different angles of incidence.

The index of refraction of the liquid is found by putting the liquid in a thin walled glass cell and proceeding in the manner

explained above. The walls of the cell being thin, the error ntroduced by them may be neglected.

Set.	*af.*	*a o.*	sin *i.*	*c k.*	*c o.*	sin *r.*	μ.
1							
2							
3							

The emergent ray is parallel to the incident ray but is displaced a distance *oh* depending on the angle of incidence, the index of refraction and the thickness of the plate.

Displacement of ray 1.
2.
3.

Experiment 64.

Determination of the Index of Refraction of a Prism.

References : Watson, §§ 345–346.

Experiments 62 and 63.

It has been shown in previous experiments that the direction of a ray of light passing from one substance into another of a different optical density is deviated from its original path so that the following relation holds true :

$$\frac{\sin i}{\sin r} = \mu.$$

It has also been shown that if the ray passes through a transparent plate with parallel faces that the emergent ray is parallel to the incident ray.

If the faces of the plate are not parallel the emergent ray will not in general be parallel to the incident ray, but if produced backward will make an angle with the incident ray produced forward. This angle is called the angle of deviation.

It is proved in the text that if the angles of incidence and emergence are equal, the angle of deviation is a minimum.

The amount of the deviation depends on the angle of the prism and the index of refraction of the material from which the prism is made. When the deviation is a minimum the following relation holds:

$$\mu = \frac{\sin \frac{1}{2}\ (\alpha + \delta)}{\sin \frac{1}{2}\ \alpha} \text{ (Watson, § 346.)}$$

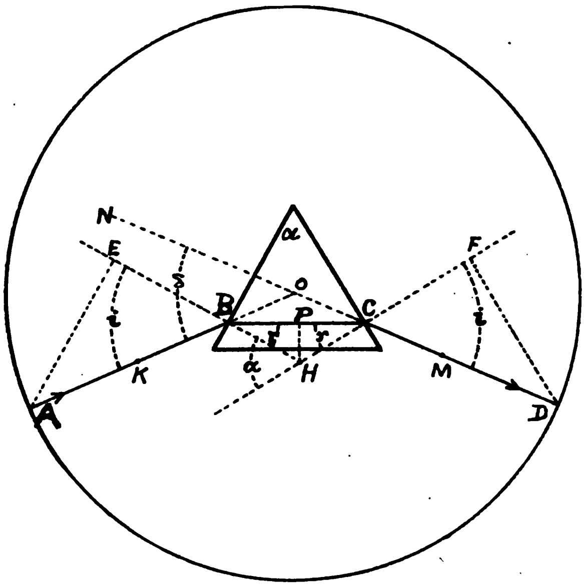


FIG. 29

in which δ is the angle of minimum deviation, and α is the angle of the prism.

Describe a circle, on a page of your note book of which the radius is about 10 cm. Stick a pin at some point A on the circumference and at a second point K on a radius OA, 5 or 6 cm. from A. Place the prism approximately in the center of

the circle. Place the eye so that, looking through the prism, the pins A and K appear to be along the line of sight. Rotate the prism about a vertical axis with the fingers, following the images of the pins with the eye until on turning the prism in either direction the line of sight comprising the images of the two pins A and K will make a greater angle with the real line connecting the pins.

The prism will then be placed so that the angle of deviation is a minimum.

Place two pins along the line of sight as at M and D. Draw an outline of the prism on the paper and remove the prism. Draw the lines DM and AK intersecting the traces of the prism faces at C and B. Produce the lines until they intersect at some point O. The NOA angle is the angle of minimum deviation.

Draw perpendiculars to the prism face traces at C and B. The angle at the intersection H will be equal to the angle of the prism. Connect the points B and C and drop a perpendicular from H to the line thus obtained. Drop perpendiculars from the points A and D to the lines BE and CF.

The angles ABE and DCF are the angles of incidence and emergence. Show that they are equal. Show also that the angles HBC and HCB are equal.

Determine the angles a and δ and compute the index of refraction of the prism.

Tabulate data and results as follows :

$AE =$ cm.	$AB =$ cm.	$\sin i = \quad .i =$
$FD =$ cm.	$CD =$ cm.	$\sin i' = \quad .i' =$
$HP =$ cm.	$BH =$ cm.	$\sin r = \quad .r =$
$HP =$ cm.	$CH =$ cm.	$\sin r' = \quad .r' =$
$KN =$ cm.	$KO =$ cm.	$\sin \delta = \quad .\delta =$
		$a =$

$$u = \frac{\sin \frac{1}{2}\ (a+\delta)}{\sin \frac{1}{2}\ a} =$$

Experiment 65.

MEASUREMENT OF THE ANGLES OF A PRISM USING SPECTROMETER.

INDEX OF REFRACTION OF A PRISM.

References : Watson, §§ 336, 345–346, 357.
Experiments 62 and 64.

This experiment may be divided into two parts, the first part being to determine the angles of a prism and the second to find the index of refraction of the prism. The methods involve the principles already described.

I.

In order to find the angles of the prism it is first necessary to adjust the spectrometer.

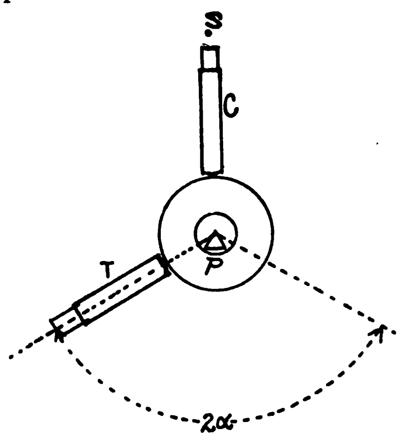


FIG. 30

Adjust the telescope T by focusing for parallel rays using some distant object, at the same time adjusting the position of the cross hairs by means of the adjustable eyepiece until they are distinct when the image of the distant object is distinct and

there is no shifting of the cross-wires over the image when the eye is shifted about in front of the eye piece.

Next swing the telescope about its axis until it is in line with the collimator C and the slit in the end of the collimator tube is visible. Then adjust the length of the collimator tube until the slit is sharply focused and no parallelax is observable. If the table P is not adjustable the instrument is ready for use.

Place the prism well back on the table as shown in the figure, with the refracting angle to be measured toward the collimator. The edge should be vertical.

Move the telescope until the image of the slit is seen reflected from one face of the prism. Set the cross-wires on the image and read the vernier of the instrument. Revolve the telescope about its axis until the cross-wires are set on the image of the slit reflected from the opposite face of the prism. Read the vernier. The angle through which the telescope has been moved is twice the angle of the prism.

Shift the position of the prism so that the vernier will not read the same as before and make a second determination of the angle.

Make three determinations of each angle of the prism.

II

Mount the prism approximately on the center of the table with the refracting edge vertical, one face being in the path of the parallel rays from the collimator. Revolve the telescope about the axis of the instrument until its axis lies within the refracted beam. If white light be used the refracted light will be a spectrum. If monochromatic light be used a monochromatic image of the slit will be seen. For this experiment sodium light is to be used. A Bunsen burner tipped with asbestos soaked in a common salt solution will answer.

Having found the refracted image of the slit rotate the table carrying the prism at the same time following the image by ro-

tating the telescope, until a position is found such that if the table carrying the prism be rotated in either direction the deviation of the ray will be increased. The deviation is then at a minimum.

Set the cross wires on the image and read the vernier. Remove the prism from the table, rotate the telescope and view the slit direct. Read the vernier again. The angle turned through by the telescope gives the required angle.

Make two independent observations of the angle of minimum first with the light incident on one face adjacent to the refracting edge, then on the other face.

From the mean of these angles and the refracting angle of the prism compute the index of refraction for the prism. Tabulate all observations carefully and show how computations were made.

Experiment 66.

TO DETERMINE THE FOCAL LENGTH AND RADIUS OF CURVATURE OF A CONCAVE MIRROR.

References: Watson, § § 337–339.

The *principal focus* of a mirror is that point at which parallel rays incident on the mirror parallel with the axis will intersect. The *focal length* of the mirror is the distance from the vertex of the mirror to the principal focus. The focal length is equal to one half the radius of curvature. The above applies to mirrors of small aperature, that is, the radius of the reflecting area is small compared to the radius of curvature. When this is not true the rays do not cross at a point but along a surface, called a caustic. (Watson, § 339).

Place the mirror and light source with its adjustable support on the optical bench, with a ground glass screen between them.

So adjust the position of the screen as to receive an image of the source.

Measure carefully the distance from the image and from the luminous source to the vertex of the mirror. Make six su-

observations for different distances from the source of light to the mirror, and compute f from each pair of observations, and also r.

If u and v be the distances of the light source and screen respectively from the mirror, then

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} = \frac{2}{r}$$

If an object be placed at the center of curvature the rays striking the mirror face will be reflected directly back on themselves, since they will strike the surface normally, and the image will also be at the center of curvature.

To test this take the screen off the bar and move the light support to such a position that the image of the tip of a wire corresponds with the actual tip. When this position is obtained the object and image will hold their relative positions no matter how much the observer may move his eyes.

Measure the distance from the point to the vertex of the mirror. This will be the required radius.

Make four or five independent determinations of r in this manner.

For a mirror of a given radius of curvature, assuming an object, show how to construct the image graphically.

Prove that

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

Set	u.	v.	f.	r.	Direct measurements of r.
1					
2					

Mean computed r.

Mean observed r.

Experiment 67.

FOCAL LENGTH OF CONVEX LENSES.

PARALLEL RAY METHOD.

References: Watson, § § 348–349.

The focal length of a thin convex lens is defined as the distance from the optical center to the point on the axis of the lens at which rays incident on the opposite face of the lens parallel to that axis are brought to a focus. It must also be remembered that rays passing through a thin parallel plate are not deviated and that the displacement may be neglected if the plate is very thin. (Watson, § 342). Close to the optical center of the lens the faces may be considered parallel

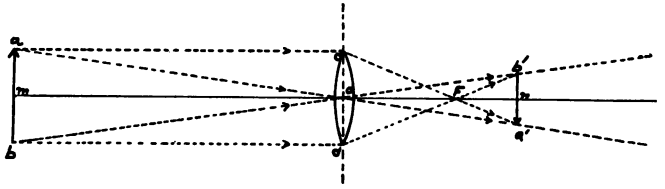


FIG. 31

From the above statements the law of the lens may be obtained for a thin lens of small aperture.

Let *o* be the optical center of a thin lens of which the principal focus is at *F*, a distance of *f* from *o*.

An object *ab* is situated at a distance *om* from *o*. Let this distance be called *u*. The image of *ab* will be at *a'b'* a distance *on* from *o*. Let the distance *on* be called *v*. Assume directions opposite to that of the incident light as positive and those in the direction of the incident light as negative.

From the similar triangles *aob* and *a'o'b'*

$$\frac{ab}{a'b'} = \frac{u}{-v}$$

and from the similar triangles *cdf* and *a'b'f*

$$\frac{cd}{a'b'}=\frac{-f}{-v+f}=\frac{u}{-v} \quad \text{since } ab=cd.$$

This expression may be changed into the typical form

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

If the object be at infinity the incident rays will be parallel and $\frac{1}{u}$ will be zero, therefore $\frac{1}{f}=\frac{1}{v}$ from which $f=v$.

Point the optical bench, carrying the lens and ground glass screen, at an open window in such a manner that some distant object may be focussed on the screen.

Get the best possible focus and measure the distance from the lens to the screen. This gives the focal length direct. Make several independent settings of the screen, noting in each case the distance measured.

Turn the lens so that the faces be reversed and make three or four more determinations.

Find the mean of all the readings for the mean focal length.

Find the focal lengths of several convex lenses.

Experiment 68.

Focal Length of Convex Lenses.
Object and Image at Finite Distances from the Lens.
Relation of Size of Object and Image.

References: Watson, §§ 348–349.

Experiment 67.

In this experiment the apparatus required consists of the lenses to be tested, a luminous source, a screen and an optical bench.

If u and v be the respective distances of the object and image from the lens, of which the focal length be f then

$$\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$$

Place the lens to be tested between the ground glass screen and the luminous source. Directly in front of the luminous source place an opaque screen with a small sharp opening.

Consider the opening as the object.

Adjust the positions of the lens and ground glass screen until a distinct image of the edges of the object is obtained on the ground glass screen. Measure the distances from the object to the lens and from the image to the lens.

Measure also one dimension of the object and the corresponding dimension on the image.

Change the position of the lens by a few centimeters and again set the screen to receive a distinct image. Make measurements as before.

Get eight sets of measurements as directed above; four sets with one face of the lens toward the object and four sets with the opposite face toward the object.

Note the effect on the position of distinct focus in one set when red or blue light instead of white light are used.

Show, by diagram, how to find the position and size of the image, when the object, its size and distance from the lens, and the focal length of the lens are given.

Show from the diagram that

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

and also that

$$\frac{o}{I} = \frac{u}{v}$$

where I is the size of the image and o is the size of the object, while u and v are respectively the distances of the object and image from the lens.

Arrange data as follows :

Set No.	u.	v.	f.	o.	I.	$\frac{u}{v}$	$\frac{o}{I}$

Experiment 69.

Focal Length of a Convex Lens.

Changing Position of Lens.

References : Watson, § 349.

Experiment 67.

The apparatus needed is the same as in experiment 68.

The general equation for the convex lens is

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$ (1) where u and v are the distances of the object and image from the center of the thin lens.

If L be the distance from the screen to the object then

$$-u + v = L$$

or $u = -(L - v)$ (2)

If this value of u be substituted in equation (1) we have

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{L - v} \quad (3)$$

The solution of (3) for v gives $v = = \frac{L}{2} + \frac{1}{2}\sqrt{(L^2 - 4fL)}$ (4) which shows that for a given lens and a given fixed distance between the object and screen, there are two positions of the lens, symmetrically situated with respect to the mid-point between the object and screen, which will give an image on the screen, provided L is greater than $4f$.

For the first position of the lens producing an image on the screen $\frac{1}{f}=\frac{1}{v}-\frac{1}{u}$ and for the second position of the lens producing an image, L remaining the same $\frac{1}{f}=\frac{1}{v_1}-\frac{1}{u_1}$

From symmetry $-u_1=v$ and $v_1=-u$.

Let the distance through which the lens must be moved from the first to the second position be denoted by a, then

$a=u_1-u=v-v_1=-u-v$. (5) $L=-u+v$ (2)

From equations (1), (2) and (5) $f=\frac{L^2-a^2}{4L}$

DIRECTIONS FOR PERFORMING EXPERIMENT. With the lens between the object and the screen, find some position of the lens giving a good image. Note the position of the lens.

Without moving the object or screen, find another position of the lens producing a clear image on the screen. Note the second position of the lens. The distance from the object to the screen is called L and the distance the lens was moved is called a. From observed values of L and a compute f.

For a second set change the distance L between the object and the screen, and find a new value of a.

Get six sets of readings, three with the lens with one face toward the screen and three with the lens reversed.

Set No.	L.	a.	f.
1			
2			
3			
4			
5			
6			

Lens Mean value of f

Experiment 70.

FOCAL LENGTH OF A CONCAVE LENS. METHOD OF DIVERGENT RAYS.

References : Watson, § 348–349.

Experiment 67.

A concave lens is a divergent lens. That is, if a parallel beam of light pass through a thin concave lens of small aperture, parallel with the axis, it will diverge from the opposite face of the lens in such a way as to seem to come from a point on the first side of the lens. This point is called the principal focus of the lens and its distance from the lens will be the focal distance f of the lens.

In a manner similar to that used in experiment 67 it may be

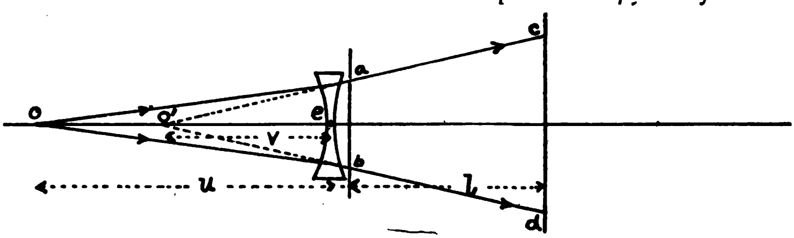


FIG. 32

shown geometrically that for concave lenses the following relation holds between the conjugate focal distances u and v, and the principal focal distance f.

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

Let a concave lens be mounted in front of a small bright source of light O situated on the axis of the lens. If an opaque screen through which two small holes a and b, 2 or 3 cm. apart be mounted immediately back of the lens two bright spots, c and d, will be found on a screen placed some distance back of the lens.

The rays of light Oa and Ob after passing through the lens and holes in the screen take the directions ac and bd as if coming from some point O' on the axis. The point O' is therefore the virtual image of the source O.

The distance $Oe=u$ from the object to the lens may be measured directly, but the distance $O'e$ cannot be so measured. The distance $O'e=v$ may be computed from the similar triangles $O'\ a\ b$ and $O'\ c\ d$.

Place a screen directly behind the lens being careful to get the holes a and b placed as nearly symetrical with regard to the axis of the lens as possible. Place the screen S at such a distance from the lens that as clear spots of light be formed as possible and yet make the distance between them quite a good deal larger than between the holes in the screen.

Measure carefully the distances between the centers of the holes a and b and between the centers of the spots c and d, also the distance l between the two screens and the distance from the object to the lens.

From the distances ab, cd, and l compute v. Having obtained v compute the focal length of the lens, being careful to regard signs.

Make several determinations of f changing the distances u and l.

Prove the formula

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

geometrically.

Tabulate data carefully.

Find the mean f of the lens.

Experiment 71.

FOCAL LENGTH OF A CONCAVE LENS.
AUXILIARY LENS METHOD.

References: Watson, §§ 348, 350.

Experiments 67 and 70.

The method here used for finding the focal length of a concave lens requires the use of an auxiliary convex or converging lens properly chosen

The operation is as follows. Find the position of image produced by the converging lens, and measure its distance v from

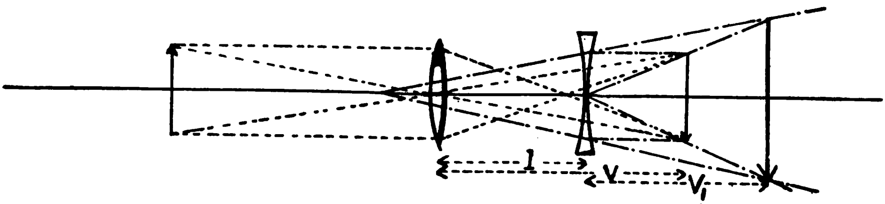


FIG. 33

the lens. For practical reasons so adjust the position of the object that its distance from the lens is considerably greater than the image's distance.

Place the concave or diverging lens between the convex lens and the screen and read just the position of the screen until a new image is obtained.

Measure the distance v_1 of the screen from the concave lens. Measure the distance l between the two lenses.

As shown in the diagram the image produced by the convex lens may be considered as a *virtual* object for the concave lens. Its distance from the concave lens will be $v - l = u_1$.

For the concave lens $\dfrac{1}{v_1} - \dfrac{1}{u_1} = \dfrac{1}{f_1}$.

Make four determinations of the focal length f_1, changing the

position of both lenses, and also the distances between the lenses.

Note that when the converging lens is moved a new image due to it must be found in order to get a new value of v.

Care must be taken regarding signs.

Arrange data thus :

v.	l.	$u_1 = v - l$.	v_1.	f_1.

Average value of f_1.

PART V.

ELECTRICITY AND MAGNETISM.

Experiment 80.

MAGNETIC FIGURES WITH IRON FILINGS.

References: Watson, §§ 415–420.

The experiment shows the direction, distribution, and characteristic tendencies of magnetic lines of force by means of iron filings.

1. Place a bar magnet in a vertical position in the frame beneath the horizontal glass plate. Sift iron filings evenly over the plate and tap it. Do not use too many filings. Note the arrangement of the filings in radial filaments. Are there any indications whether the lines of force are horizontal or otherwise?

Obtain filing figures due to two vertical magnets a few centimeters apart, (*a*) with unlike poles up; (*b*) with like poles up; (*c*) with a magnet and a soft iron bar. Describe (or draw) and interpret the arrangements of filings.

2. Proceed in like manner with, (*a*) a two pole magnet placed horizontally against the under side of the glass; (*b*) a consequent pole magnet; (*c*) two magnets with like poles first oppositely directed, then in same direction; (*d*) a magnet and a *soft iron* ring in any position desired; (*e*) a horse shoe magnet. Locate straight lines and neutral points. How is variation of field strength indicated? Explain.

3. Place a small compass near the magnet pole, then move it so that the motion at any point of the path traced is in the same direction as the needle's length at that point. Draw the line, thus traced, upon the sketch already made. Show by an arrow head the direction in which the positive pole of the needle

pointed. In like manner draw a line in some other direction from the magnet. Note whether the lines of force enter or leave the positive end of the magnet.

4. State wherein the figures indicate the two characteristic tendencies of magnetic lines of force, viz., they tend to shorten longitudinally and to repel each other laterally. Why do the iron filings map out the lines of force?

Experiment 81.

DETERMINATION OF THE POLE STRENGTH OF TWO MAGNETS.

References: Watson, §§ 416, 418, 421–423.

The experiment consists in finding the pole strengths of two magnets by determining their product mm_1 and their ratio m/m_1. It depends on the law of force action between poles.

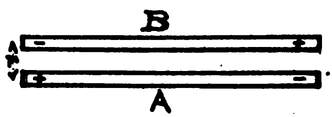


FIG. 34

Determine approximately the position of each pole. Mark these points with chalk using + and — for the positive and negative poles respectively.

I.

Product of pole strengths. Balance A, the lighter of the two magnets with its axis horizontal on one pan of a platform balance. Adjust the magnet B upon outside supports so that it is immediately above magnet A and parallel with it, but separated from it by about 3 or 4 cm. This distance should not be greater than one-fourth the distance between poles of the shortest magnet. Determine the force in grams weight necessary to overcome the attraction between the two magnets and also the force necessary to overcome the repulsion when they

are placed with like poles opposite. Determine the distance between the two attracting (or repelling) poles.

N.B. This is the distance between centers.

Tabulate data and results as follows:

Vertical distance between axes of magnets with unlike poles near each other, $d_1 =$ cm.

Force necessary to balance the attraction of the two pairs of poles in grams wt. $=$ *g*.

$f_1 =$ dynes.

Product of poles strengths mm_1 $=$

Vertical distance between axes of magnets with like poles near each other, $d_2 =$ cm.

Force necessary to balance the repulsion of the two pairs of poles in grams wt. $=$ *g*.

$f_2 =$ dynes.

Product of pole strengths mm_1 $=$

Average product of pole strengths $=$

Draw a diagram showing graphically all the gravitational and magnetic forces for equilibrium. What approximations are made? Discuss fully their influence on the results.

II.

Ratio of pole strengths. Place the magnet A in a vertical position with one of its poles about 8 cm. to the *east*, magnetically, of the middle point of a good compass. Place the magnet B also in a vertical position with one of its poles to the *west* of the middle point of the compass. Move B towards or from the compass until the latter points in the same direction as it did when both magnets were absent. Measure the distance of the poles of both magnets from the middle of the compass. Repeat these observations with the magnet pole of A about 10 and 12 cm. distant from the compass.

Tabulate data and results as follows :

	1	2	3
Distance of pole *A* from compass			
" " *B* " "			
Ratio of pole strengths			

Draw diagram graphically illustrating all the magnetic forces acting on the compass needle.

III.

Pole Strength. From the results of the preceding experiment compute the pole strength of each of the two magnets experimented upon.

Pole strength of $A =$

Pole strength of $B =$

Experiment 82.

TO DETERMINE THE MOMENT AND THE POLE STRENGTH OF A MAGNET.

References : Watson, §§ 422–423, 427.

If a two-pole bar magnet is placed in air where it is free from disturbing influence the field at all points equidistant from its poles is parallel to the axis of the magnet and directed from the positive toward the negative pole. The field strengths at these points are inversely proportional to the cubes of their distances from the poles. (See conclusion derived below).

If the bar magnet is placed horizontally with its positive pole pointing northward there will be a neutral point on either side where the horizontal component H of the earth's field northward is equal and opposite to the southward field f of the magnet. This neutral point may be found by noting where a com-

pass needle or a more delicately suspended magnet shows, by pointing indifferently in any direction, that the resultant field at the point is zero. The distance r of this point from the poles may then be measured directly or may be computed from its distance d, from the center of the magnet and the half length between poles.

In the figure let p be the neutral point where H is equal and opposite to f, the latter being the resultant of the two fields f_1 and f_2 due respectively to the north and south poles of the magnet. Let the distance between the poles be $2l$.

From similar triangles in the figure,

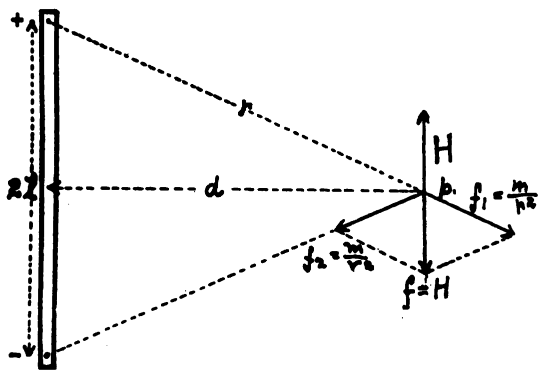


FIG. 35

$$\frac{2l}{r} = \frac{f}{f_1} = \frac{H}{m/r^2}; \text{ or } \quad 2ml = Hr^3.$$

Then since $2ml = M$, $M = Hr^3$ and $m = \dfrac{M}{2l}$

The value of H at the station where the experiment was performed may be obtained from the known value of H at a given place by means of a magnetic pendulum vibrated at the two places. The field intensities are inversely proportional to the squares of the periods. (Watson, §427).

Find the neutral point on each side of the given magnet, measure the distances, r and l and compute m and M.

Experiment 83.

TO DETERMINE THE PRODUCT MH.

References: Watson, §§ 423–425, 427–428.

Ames & Bliss, pp. 356–364.

A magnet suspended by a torsionless fibre will assume a position tangential to the horizontal component of the earth's field, (See Watson §, 429) if the axis of the bar be horizontal.

If the magnet be displaced through a small angle (so that it may have $S.H.M.$) about the axis of suspension it will vibrate. The square of its periodic time will be directly proportional to its moment of inertia K about the axis of suspension, and inversely proportional to the strength of the earth's horizontal component H, and the magnetic moment M of the bar.

The form of the equation is similar to that in the case of the pendulum.

The gravitational pendulum equation is $T^2 = \dfrac{4\pi^2 l}{g}$.

The magnetic pendulum equation is $T^2 = \dfrac{4\pi^2 K}{MH}$.

The moment of inertia K in the above equation may be shown to be $=$ mass $\times \left(\dfrac{l^2}{12} + \dfrac{r^2}{4}\right)$; where l and r are respectively the length and radius of the bar. Watson, § 85.

From the above equation it may be seen that if H is known at one station it may be found at a second station by finding the periodic time at both stations, the quantities K and M remaining constant.

The object of this experiment is to find the magnetic moment

of the magnet used, the distance between its poles, its pole strength, and the strength of the earth's horizontal component H at two or more points, H being given at one station. If experiment 84 is also performed H may be found by elimination between two simultaneous equations.

Make a note of the stations used and also the magnet number.

Find the periodic time by the same method as used in the experiment on the pendulum.

DATA.

No. of transits to right.	Time of transit to right. Hr. min. sec.	Number of vibrations.	Time interval. Min. sec.	Periodic time T.
1	11 12 5	51— 1	6 20	
11	11 13 21	41—11	3 48	
21	11 14 38	31—21	1 15	
31	11 15 53			
41	11 17 9	90	10 83	
51	11 18 25		683	7.59

Mass of magnet =
Length of magnet =
Diameter of magnet =
Moment of inertia
of magnet=

Dist. between poles of magnet=
Value of H at =
Value of $M H$ =
Value of M =
Value of m =

Experiment 84

DETERMINATION OF THE RATIO M/H.

References: Watson, § 426.

Tory and Pitcher, pp. 139–142.

A small compass needle suspended horizontally will assume a position such that its axis will be parallel with the lines of force in the magnetic field in which it is placed.

If the field used is that of the earth, the magnet will assume

a north and south position. Let a bar magnate be placed in the same horizontal plane with the small magnetometer needle above referred to, so that its axis is in the horizontal plane through the poles perpendicular to the horizontal component of the earth's field H, through the center of the magnetometer needle.

Then at the magnetometer needle there will be two fields at right angles to each other, one due to the earth and the other due to the bar magnet. The field due to the magnet will depend on the strength of the magnet poles and their distances from the needle.

The needle will set itself so that its axis will be in the direction of the resultant field. Therefore if H, the strength of the horizontal component of the earth's field be known the value of the field at right angles to it may be found and also the magnetic moment M of the magnet.

The equation giving the relation between the field H due to the earth and that f due to the magnet in the above position,

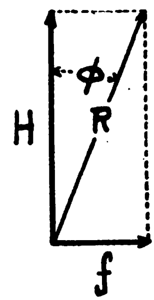


FIG. 36

is $$\frac{f}{H} = \tan\theta$$

If L is the distance from the needle to the center of the bar and l is the distance from the center of the bar to either pole, then from the law of force action, the poles being $+m$ and $-m$

$$f=\frac{m}{(L+l)^2}+\frac{-m}{(L-l)^2}=\frac{4mlL}{L^4-2L^2l^2+l^4}$$

$$=\frac{4mlL}{(L^2-l^2)^2} \text{ from which } \frac{f}{H}=\frac{\frac{4mlL}{(L^2-l^2)^2}}{H}=$$

$\tan\theta$. But $2ml=M$, the magnetic moment.

$$\therefore \frac{M}{H}=\frac{(L^2-l^2)^2}{2L}\tan\theta.$$

Place the magnetometer so that the damping vane, which is used as a pointer, is parallel with and above the line connecting

the zeros. The instrument may be levelled by means of the three screws attached to its base. Run a wooden bar through the rectangular openings in the base of the instrument. This bar would then be at right angles to the direction of the earth's field at the magnetometer needle.

Place the magnet to be tested on the bar with its axis parallel with the bar, the center of the magnet being far enough from the needle to produce a deflection of at least 25°. Read the deflection and the distance from the needle to the center of the magnet. Turn the magnet end for end and read again. Repeat these readings. Then place the center of the magnet at such a distance from the needle as to increase the deflection by 15° or 20° and make another set of readings as above. Then make two sets of readings with the magnet on the opposite side of the magnetometer using the same distances from the needle to the magnet as above. If H be given, from the data taken the magnetic moment may be computed.

If experiment 83 has been performed with the same magnet at the same station, both M and H may be determined.

Find distance between poles of the magnet and compute m, the pole strength of the magnet.

The data may be tabulated as follows:

Number of magnet . Total length of magnet = cm.

Distance between poles $=2l=$

$H=$. $M=$. $m=$

Center of magnet ..cm. east of magnetometer.	Magnetometer reading in degrees.		Mean deflection.	tan θ.
	N	S		
N pole E				
N pole W				
N pole E				
N pole W				

$$\frac{(L^2-l^2)^2}{2L} =$$

Experiment 86.

ELECTROSTATIC FIELDS.

References: Watson, §§ 438–440, 441.

When a rubber or ebonite rod is rubbed with a woolen cloth or cat's fur it is found that both the rod and the cloth will attract pieces of paper or other light substances. The rod and cloth are said to be electrified. In a following experiment it will be shown that the bodies are electrified in a different manner. The rod is said to be negatively electrified and the cloth or fur positively electrified.

We have already seen that in the case of magnetic poles there are fields of magnetic force surrounding them. In an analogous manner there are electrical fields surrounding bodies charged with static electricity. In these fields there are electrostatic lines of force. It is the object of this experiment to study those lines of force.

The experimental study of electrical fields of force may be pursued by using an indicator consisting of a short rod of some non-conductor terminated at each end by a gilt pith-ball and mounted to swing freely about an axis. For some purposes an aluminum wire terminated by pith-balls may be used.

If the non-conducting indicator is used the two pith-balls are to be charged oppositely by contact with the two terminals of an electrical machine. The pith-ball which has been charged positively can be determined by bringing the indicator near a hard rubber rod which has been electrified by friction with fur or almost any other non-conductor.

If such an indicator is brought into an electrical field the positively charged ball will be acted upon by a force in the direction of the lines of force of the field and the negative ball by a force in the opposite direction, hence if free to revolve the indicator will come to rest parallel to the lines of force with the *positively charged pith-ball pointing in the positive direction*.

If the conducting indicator of aluminum is used it need not be given a charge, but when put into an electrical field it will be charged by induction. It will point along the lines of force the same as the non-conducting indicator except that the positive direction of lines of force cannot be determined by it.

By means of one of these indicators determine the direction of the lines of force for several different fields in the immediate neighborhood of the following:

1. A charged sphere.
2. A long charged cylinder with hemispherical ends.
3. Two spheres or cylinders charged alike and placed a few centimeters apart.
4. Two spheres or cylinders charged oppositely and placed near each other.
5. A charged sphere or cylinder near a "grounded" metal plate.
6. An ebonite rod which has been charged in spots by being held in contact with the poles of an electrical machine.

Illustrate the results of these experiments by diagrams. Draw two or more equipotential surfaces on each diagram.

Experiment 87.

THE GOLD LEAF ELECTROSCOPE.

References: Watson, §§ 440–442.

Read carefully the articles referred to above and study the method of electrification by induction.

I

(1) Charge a gold leaf electroscope by induction using a rubber rod which has been rubbed with wool or fur.

After the electroscope has been charged note the effect on the leaves, of bringing near the knob or plate of the electroscope, either the rubber rod or the wool. Do not bring the rod too near the electroscope.

II

(2) Discharge the electroscope. Charge the electroscope again by induction this time using the wool or fur as the carrier of the inducing charge. Prove that the electroscope is charged oppositely to what it was when the rubber rod carried the inducing charges.

Give all the steps in charging the electroscope together with explanatory diagrams of each step showing distribution of charges and lines of force.

Experiment 88.

FARADAY'S ICE PAIL EXPERIMENT.

References : Watson, §§ 440–442, 444–445, and Experiment 87.

The object of this experiment is to show that when one kind of electricity is induced an equal amount of the opposite kind is also induced.

Connect a hollow sphere or a hollow cylinder, supported on an insulating (Watson, § 439) stand with the knob of a gold leaf electroscope by means of a bare copper wire.

See that the apparatus is completely discharged.

(The electroscope will indicate any charge on the isolated system.)

I

Obtain a charge on a proof plane or test sphere (a metal sphere with an insulating handle) from an electrical machine and note carefully the action of the electroscope during the following operations :

(1) Bring the charged body near the cylinder.

(2) Hold it well within the cylinder but not making contact. Move charged sphere about within the cylinder taking care not to make contact.

(3) Finally touch the cylinder with the charged sphere.

II

Ground the cylinder and electroscope so that they are in a neutral state again. Obtain another charge on the insulated test sphere and proceed as follows, noting the indications of the electroscope :

(1) Introduce the charged sphere within the cylinder, taking care not to make contact, as before.

(2) Ground the cylinder or electroscope.

(3) Remove ground and make contact between the test sphere and the insulated cylinder.

Make careful notes of each step in both sets of observations outlined above and illustrate the distribution of charges and ines of force by diagram.

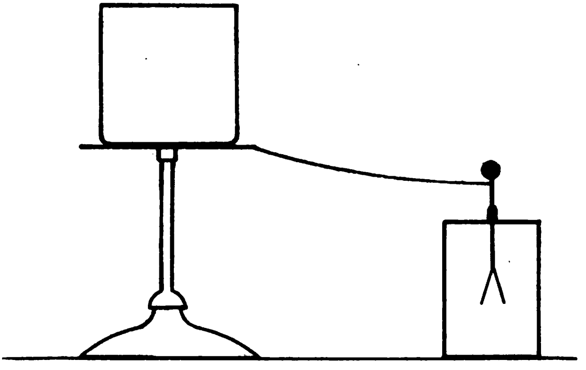


FIG. 37

Remove the connecting wire from the cylinder and electroscope.

Charge the gold leaf electroscope in the usual manner. Get a charge on the test sphere and determine its sign by means of the electroscope.

Suspend the charge within the insulated cylinder and test the signs of the induced charges on the inside and outside of the insulated cylinder by means of a second insulated test sphere and the electroscope.

Make contact between the charged sphere and the cylinder. Then test for the signs of the charges on the first sphere, the inside and outside of the cylinder.

Give a general summary in a few words of the conclusions to be drawn from the above experiments.

Experiment 90.

THE TANGENT GALVANOMETER. I.

References : Watson, §§ 476–478.

A. Formulæ and theory of adjustment.

The deflection of the needle of a tangent galvanometer depends upon the relative values of the directing force due to the earth's field H acting upon the needle, and the deflecting force due to the field H_c produced by the current. When current flows in the coil the needle turns until its length is parallel to the resultant of the two component fields. It is essential that the galvanometer be set up so that these components of the resultant field will be at right angles to each other. Then $H_c/H = \tan\theta$ (1) θ being the angular deflection. The field H_c at the center of a coil carrying a current of C *c.g.s.* units is proportional to current; $\therefore\ H_c = GC$; (2). G is the proportionality factor called the "Constant of the Coil." It may be proved that $\boxed{G = \frac{2\pi n}{r}}$ (3) n being the number of turns and r the mean radius of the coil.

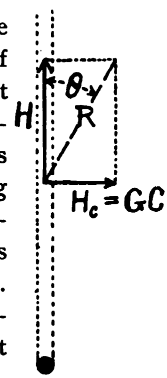


FIG. 38

Substituting GI for H in equation (1) gives $C = (H/G)\tan\theta$ (4) for current in *c.g.s.* units. For any system of units,

Current = Constant x tangent of deflection (5).

H/G is a constant for a given coil in a constant field, and is numerically equal to the current that will produce a deflection

of $45°$; since $\tan 45°$ is unity. The constant by which $\tan\theta$ must be multiplied to give the value of current is called the "Constant of the Galvanometer," or the "Reduction factor." It may be expressed in any of the following forms:

Reduction factor $= i_0 = H/G = Hr/2\pi n$ for *c.g.s.* units (6) or

$C = I_0 \tan\theta$

$$I_0 = \frac{10H}{G} = \frac{10rH}{2\pi n} \quad (7)$$ if the current is to be expressed in amperes.

Show by diagram that $H_c/H = \tan\theta$, and show that the deflection for reversed current will not be the same if H_c is not perpendicular to H.

Define the *c.g.s.* electro-magnetic unit of current, and the prac-

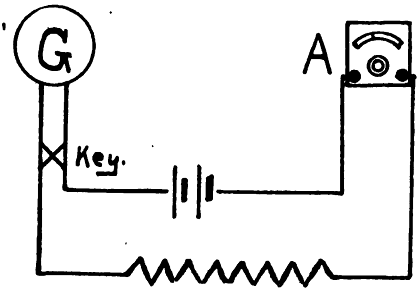


FIG. 39

tical unit. Why should the galvanometer be set up so that the plane of the coil is parallel to the lines of force of the earth's field? How determine when it is so set?

B. Procedure for adjustment.

In this equation the coefficient of $\tan\theta$ is the reduction factor, or constant of the galvanometer. Upon what does the sensitiveness of a tangent galvanometer depend, and how does it vary with each of the quantities involved?

In adjusting the tangent galvanometer for use the two important things to be accomplished are: (1) to get the point of suspension vertically over the center of the graduated circle, and (2) to set the coil with its plane parallel to the lines of the

earth's field H. The first adjustment may be made approximately by levelling the needle box by means of the adjusting screws in the base. Then, by means of current, obtain a large deflection and note whether the ends of the long pointers describe arcs of circles concentric with the graduated circle. If they do not, adjust with the levelling screws until they do.

For the first approximation to the second adjustment, turn the base of the galvanometer until the coil is approximately in the magnetic meridian. Obtain deflections (somewhere between 30° and 60°) with the current first in one direction then reversed. If the current is constant and the deflections are the same for direct and reversed current, no further adjustment is necessary. If the deflections are not equal the plane of the coil should be

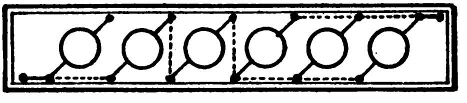


FIG. 40

turned (by turning the base) until the arcs of the deflections are equal for direct and reversed current; then, with no current note carefully the true zero, for each end of the pointer.

When the galvanometer is properly adjusted, connect a designated coil in series with a resistance and a source of current. Place in the circuit an ammeter or another galvanometer that has been calibrated so that the amperes of current may be obtained. Adjust the resistance so that the deflection is between 30° and 50°.

Take readings for each end of the pointer for both direct and reverse currents, and use the mean of the four readings for the deflection. If the currents are obtained by means of another tangent galvanometer make simultaneous readings on it and treat the readings in the same manner. If an ammeter be used the

current is to be read directly or from a calibration curve for each set of readings on the instrument to be tested.

The values of the currents having been obtained from the standard measuring instrument, and the tangents of the angles of deflections of the galvanometer to be tested having been found from a table, the constant I_0 of the assigned galvanometer coil may be computed for the particular place in which it is located.

C. Calibration of galvanometer.

Measure the current through, (1) each of two lamps separately, (2) two in parallel, and (3) two in series, (Watson, § 485). See figure 40 for a plan of a variable lamp resistance. Compare values of current and explain.

Compute the I_0 for each of the above sets of readings.

Plot a curve using values of the current as obtained from the standard instrument as abscissas and corresponding values of the tangents of the angles of deflection of the tested instrument as ordinates.

Obtain the value of the mean radius of the coil used and compute the value of H for the given station.

Then compute the value of I_0 for some other coil of the galvanometer from its dimensions and the value of H as obtained above.

Tabulate data as follows :

Galvanometer to be tested No...... Coil..........................					Standard Galvanometer or Ammeter No.			
Laboratory station.............								
Test Galvanometer......... Readings of indicator.					Standard Galvanometer or Ammeter. Readings of indicator.			
Direct	Reverse	Average	$\tan\Theta$	I_0	Direct	Reverse	Average	Current

Value of G..........

Value of H..........

Computed Constant for Coil No..........

Number of turns= Mean radius=

$G=$..............$H=$. ....I_0..............

circuit. From this it follows that in a circuit in which the *E.M.F.* is a constant the current will be inversely proportional to the total resistance. That is, in a simple circuit

$$C = \frac{E}{R} = E\frac{1}{R} \qquad (1)$$

where R is the resistance of the circuit. The term R includes all the known and unknown resistances of the circuit such as the resistances of galvanometers, batteries, resistance boxes, connecting wires, etc. If we let R represent the known resistances and R_0 the unknown but constant resistances, equation (1) may be written

$$C = \frac{E}{R+R_0} = E\frac{1}{R+R_0}$$

Put a galvanometer of known constant in series with a known

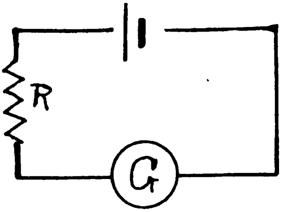


FIG. 41

variable resistance, and a constant source of *E.M.F.* A reversing switch to change the direction of the current through the galvanometer should also be in the circuit.

Make a working diagram of the connections in your note book at the time of performing the experiment.

Make a series of readings for direct and reverse currents due to eight or ten different values of the known variable resistance.

From the values of tangents of the angles of deflection and the I_0 of the galvanometer compute the current flowing for each resistance.

Draw a curve using values of the known resistances for abscissas and the corresponding values of the reciprocals of the currents for ordinates. Be careful to use a good scale for plotting.

The slope of the curve in terms of the scale used is numerically equal to the reciprocal of the *E.M.F.* of the battery. The negative intercept on the x axis gives the value of R_0 Get the *E.M.F.* from the curve. Draw conclusions.

Data may be tabulated as follows.

Station No.............. H= ....

Galvanometer No.... Coil No.... I_0=...............

Kind of cell used........ Resistance box No...... ....

Resistance.	Galv. Readings.		tan θ	C.
	Direct.	Reverse.		

Value of E from curve=...............................

Value of R_0 from curve=...............................

Use value of R_0 obtained from the curve in computing values of C.

Experiment 93.

Measurement of Resistance by Comparison.

Reference: Watson, § 485.

From Ohm's Law $C = \frac{\Sigma E}{\Sigma R}$ (1)

If a battery of constant *E.M.F.* E of which the internal resistance is R_b be put in series in a circuit with a known variable resistance R, an unknown resistance X and a galvanometer whose resistance is R the current flowing will be

$$C = \frac{E}{R+X+R_0} \quad (2)$$

where R_0 is the resistance of the battery plus the galvanometer and connecting wires.

For a tangent galvanometer

$$C=I_0 \tan \theta \quad (3)$$

$$I_0 \tan \theta=\frac{E}{R+X+R_0} \quad (4)$$

Now if the unknown resistance X be removed from the circuit and R be increased to such a value, R_1 that the galvanometer deflection is the same as before then C will have the same value and therefore the denominator of equation (4) will be unchanged.

$\therefore R+R_0+X=R_0+R_1$, from which $X=R_1-R$.

It is not often possible to get the same deflection but nearly the same deflection may be obtained. Then there may be obtained two equations of the form of equation (4).

$$I_0 \tan \theta=\frac{E}{R_0+R+X} \quad (5)$$

and
$$I_0 \tan \theta_1=\frac{E}{R_0+R_1} \quad (6)$$

Dividing (5) by (6) $\dfrac{\tan \theta}{\tan \theta_1}=\dfrac{R_0+R_1}{R+R_0+X}$

R_0 is constant but is perhaps not known. It may be computed as follows:

Leaving out the unknown X connect the battery, galvanometer and resistance box in series. Adjust the box resistance to get a deflection of about 45°. Call this resistance R'. Read the deflection then change the box resistance to R'' getting a deflection about ½ as great as before. The two equations obtained will be

$$C'=\frac{E}{R_0+R'}=I_0 \tan \theta'.$$

$$C''=\frac{E}{R_0+R''}=I_0 \tan \theta''.$$

from these two equations

$$\frac{\tan \theta'}{\tan \theta''}=\frac{R_0+R''}{R_0+R'}$$

R_0 being the only unknown may be readily computed.

Experiment. Find R_0 as outlined above then make two independent determinations of the unknown resistance X using different initial values of R.

Experiment 94.

THE SLIDE-WIRE BRIDGE.

References : Watson, § § 485, 487–488.

Tory and Pitcher, Experiment 58, pp. 182–185.

For the theory of the bridge see any of the above noted references, or any text or laboratory manual. Briefly outlined the theory is as follows :

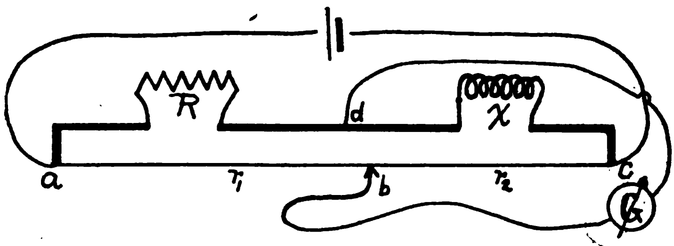


FIG. 42

In the circuit shown below, which is the most sensitive arrangement of the bridge, the current from the battery divides at a flowing to c by two paths $a\ d\ c$ and $a\ b\ c$ but none flowing through the galvanometer when the bridge is " balanced."

From Ohm's Law $pd = c\ r$. Let c_1 be the current in the branch $a\ d\ c$ and c_2 be the current in the branch $a\ b\ c$. Let pd_1 be the fall in potential between a and d and also between a and b. Let pd_2 be the fall in potential from d to c and also from b to c. Then

$$pd_1 = c_1 R = c_2 r_1 \qquad (1)$$

$$\text{also } pd_2 = c_1 x = c_2 r_2 \qquad (2)$$

$$\text{Dividing (2) by (1) } \frac{x}{R} = \frac{r_2}{r_1} \text{ or } x = \frac{r_2}{r_1} R \qquad (3)$$

Since the slide wire is supposedly of uniform cross-section the resistance is proportional to the length, therefore for r_1 and r_2 we may substitute l_1 and l_2 the corresponding lengths and equation (3) becomes

$$x = \frac{l_2}{l_1} R$$

The best ratio of the ratio arms r_2 and r_1 is one to one.

If for a balance, the contact becomes too near the end of the bridge wire then it is best to add to the opposite side a resistance equivalent to a known length of wire and get a new balance.

Measure two resistances separately, in series and in multiple.

First, change the known resistance R until, with the slider b near the center of the slide wire, a change of the smallest unit in the box R will change the direction of the deflection of the galvanometer. Then with this resistance fixed change the position of the slider until a position is found at which no deflection of the galvanometer is obtained on closing the battery key. Read the lengths of slide wire on the two sides of the slider b. The resistance of the unknown may be computed from these lengths and the value of R.

Change the value of R to some new value and get a new balance using the auxiliary wire mentioned above if the balance brings the slider too near the end of the bridge wire.

Tabulate data and results as indicated in the following table :

Description of resistance.	Segment a.	Segment b.	Resistance in box.	Resistance determined.

Compare the series and multiple resistances obtained from observations with those computed from the averages of the values of the separate resistances, according to the laws for resistances in series and in multiple.

How small a movement of the slider will produce a noticeable deflection? Name two or more probable sources of error.

Experiment 95.

CALIBRATION OF A D'ARSONVAL GALVANOMETER.

References: Watson, §§ 509-510, 515.
Carhart & Patterson, pp. 135–140.
Tory & Pitcher, Experiment No. 75.
Nichols & Franklin, Vol. II, pp. 40–41, 45.

The d'Arsonval galvanometer is an instrument which is coming into general use in commercial as well as scientific work. The underlying principle is practically that of the electrodyna-

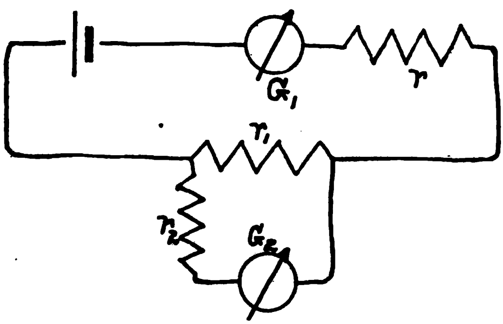


FIG. 43

mometer (Watson, § 515). In the galvanometer one coil is replaced by a permanent magnet. This feature makes it independent of the earth's field and therefore much more convenient than the tangent galvanometer for many purposes. Many types of commercial ammeters and voltmeters are modified forms of the d'Arsonval galvanometer. The theory is briefly outlined as follows:

Whenever a wire carrying a current is in a magnetic field and

has a component at right angles to that field a force acts on the wire tending to push it in a direction at right angles to the field and to the direction of the current. The direction of the force depends on the directions of the field and the current.

If a coil of wire be suspended in a horizontal magnetic field so that it may turn about a vertical axis, and a current be sent through the coil, it will turn about the axis until the return torqu e due to the wire suspension is equal to the magnetic torque.

The magnetic torque depends on the strength of the magnetic field, on the number of turns in the coil, the dimensions of the coil, and the strength of the current flowing in it.

The equation connecting these quantities varies with the type of instrument used. In some types of instruments the current is proportional to the angular deflection and in others to the

$$\cos\theta\ ;\ C=k\,\theta \text{ or } C=k\cos\theta.$$

In most cases for small deflection, the current is proportional to the number of scale divisions of deflection such that $C=Ks$ where s is the number of scale divisions of single deflection.

Connect a sensitive galvanometer whose constant is known in series with a variable high resistance, the proper reversing keys, a battery and the d'Arsonval galvanometer to be tested.

One set of readings will consist in reading of each galvanometer for direct and reverse current for a given resistance. The readings are to be repeated as a check and the means used in computing.

Make at least three sets of readings using such resistances as to give a good range of deflections.

If the galvanometer whose constant is known is nonsensitive then it will probably be necessary to connect the d'Arsonval galvanometer in shunt with a low resistance, and if the galvanometer resistance be not high enough to keep the deflections on the scale, a resistance will have to be put in series with it. The connections are outlined as follows:

Adjust the resistances until good deflections are obtained on

each galvanometer and proceed as in case one making three sets of readings.

The current in the main circuit may be found from the constant and the deflections of the galvanometer therein. The current through the d'Arsonval galvanometer may be computed from the theory of shunt circuits. (Watson, §§ 485–486).

Experiment 96.

DETERMINATION OF THE RESISTANCE OF A HIGH RESISTANCE GALVANOMETER.

A direct method for determining the resistance of a *high resistance* galvanometer is as follows :

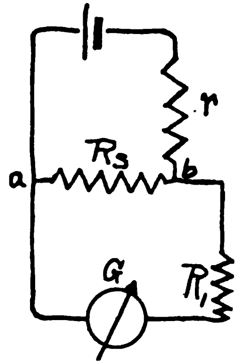


FIG. 44

Connections are made as in the figure. R_s is made so small that its resistance may be neglected in comparison with that of the galvanometer. The resistances r and R_1 are adjusted until a large deflection of the galvanometer is obtained, then R is changed so that the deflection is halved.

Call this new value of the resistance R_2. Since the resistance in the circuit has been doubled while the potential difference a/b remains practically the same, (why?) we have

$$R_2 + R_g = 2\ (R_1 + R_g)$$
$$\text{or} \quad R_g = R_2 - 2R_1$$

If R_1 was zero, the method is further simplified.

The resistance r is inserted in the battery circuit as an aid in controlling the value of the initial deflection of the galvanometer.

If a gravity cell is used, or any other cell of fairly high resistance that does not polarize, the cell may be simply short-circuited by a wire having a resistance of a few tenths of an ohm.

Experiment 97.

RESISTANCE OF A CELL BY THE HALF-DEFLECTION METHOD.

The connections are shown in the diagram. A sensitive galvanometer G is shunted with a wire R_s whose resistance is small enough to be neglected. The resistance R_1 is varied

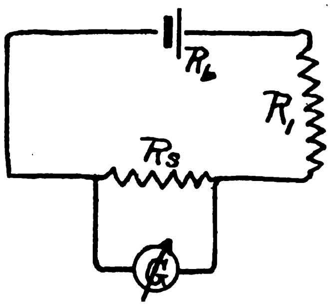


FIG. 45

until a good deflection is obtained. R_1 is then changed to R_2, such a resistance that the deflection is halved.

Since the resistance of the battery circuit in the second case is twice that in the first case, (why?) we have

$$R_b + R_s + R_2 + r = 2\ (R_b + R_s + R_1 + r)$$
$$R_b = R_2 - 2R_1 - r.$$

where R_s is neglected, and r stands for the total resistance of the connecting wires in the battery circuit.

Experiment 98.

POTENTIAL DIFFERENCE MEASUREMENT.

Reference: Watson, § 490.

The potential difference between two points in a circuit is defined at the work done in transferring a unit quantity of plus electricity from one point to the other. From Ohm's Law it follows that the potential difference between two points between which there is no *E.M.F.* along the path travelled may be

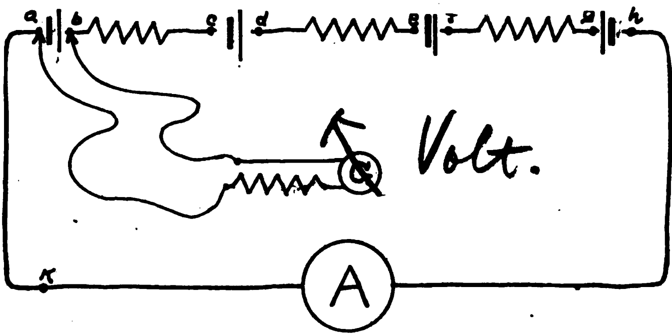


FIG. 46

expressed as follows : $pd = cr$ in which pd is the potential difference, c the current flowing and r the resistance between the points considered. Whenever a current flows through a resistance there is always a disappearance of electrical energy. The energy reappears in some other forms as in heat.

The *E.M.F.* of a battery or a dynamo is equal to the greatest possible potential difference between its terminals ; that is, when the generator is allowed to give no current, being on "open circuit." As soon as the battery or dynamo is allowed to give current, the circuit being closed, the difference of potential between its terminals is no longer equal to its *E.M.F.* but is less than the *E.M.F.* by the amount of energy used up in sending current through the generator itself, the generator

having resistance. The energy used up inside the dynamo or battery will be equal to the internal resistance multiplied by the current flowing. From the above we get the following expressions for a simple circuit.

When no current is flowing $pd = E$ between the generator terminals.

When a current is flowing then $pd = E - cr_b$ where pd is the potential difference between the generator terminals, E the $E.M.F.$ of the generator, r its resistance and c the current flowing through it.

If there is more than one source of $E.M.F.$ in a circuit it may be that the current will flow through one generator in a direction opposite to that in which it would send current if free to act alone. If this is the case the pd between its terminals will be expressed by the following relation : $pd = E + cr$, because the pd must not only be sufficient to send current through the cell owing to its having resistance, but also to overcome an opposing $E.M.F.$

Instruments used to measure $E.M.F.$ and pd are called potential galvanometers or voltmeters.

Such instruments must have comparatively high resistances and must be sensitive since very little current is supposed to flow through them. If such an instrument be placed in series with a generator the current flowing is very small, consequently the loss of potential within the generator is also very small and the pd is very nearly equal to the $E.M.F.$ of the generator.

If a potential galvanometer or a voltmeter be shunted around a resistance, very low in comparison, the current flowing through the instrument will be negligible in comparison to that flowing through the resistance and the pd between the terminals of the resistance will be practically undisturbed by the presence of the potential measurer. (Theory of shunts, Watson, § 485).

Suppose a high resistance galvanometer of the tangent or d'Arsonval type be in shunt with a resistance, around which the

pd is wanted. Then $pd = Cr$. (1)
also the current through the galvanometer

$$C_g = \frac{pd}{R^g} = I_0 \tan \theta \text{ or } Ks. \quad (2)$$

according to the type of galvanometer used, R_g being the total resistance in the galvanometer branch of the circuit.

From equation (2) $pd. = R_g I_0 \tan \theta$ or $R_g Ks$. (3)

Equation (3) shows that the *pd* is proportional to the $\tan \theta$ or the number of scale divisions of single deflection, the products $R_g I_0$ or $R_g K$ being the potential constants of the instrument.

I.

Connect to send current from one or two cells through a tangent galvanometer or ammeter and a resistance box. Connect the potential galvanometer to the terminals of the resistance, or a part of known value. Observe the deflections of both galvanometers for five or six different parts of the scale.

Tabulate observed data and the corresponding computed currents and potential differences.

Plot a curve with volts as ordinates and scale readings of potential galvanometer as abscissas. From this calibration curve the number of volts corresponding to any given deflection may be easily found. If the line is straight find the fraction of a volt represented by each large scale division. Are scale readings proportional to potential differences? Why should the resistance of a voltmeter be comparatively very high and of an ammeter comparatively very low?

Give a working diagram of the connections.

II.

Potential-Resistance Diagram of Circuit.

Connect four cells, three resistances, and an ammeter or non sensitive galvanometer in series as shown in the figure. Note that one of the cells is so connected as to oppose the other

three. Connect the point *a* to the gas pipe. Its potential will then be zero. Connect the potential galvanometer to points *a* and *b*, and observe deflection ; then connect to points *b* and *c* and observe the deflection as before *noticing particularly* whether the potential *rises* or *falls* from *b* to *c*. In like manner observe the potential galvanometer readings when connected successively to *c* and *d*, *d* and *e*, etc., to *k* and *a*. The deflection for current in the main circuit should be observed occasionally to determine whether the current remains constant or not. When the *pd* and current have been measured for closed circuit, break the circuit and measure the *E.M.F.* of each cell.

Tabulate the observed and computed data as indicated below. Plot a potential-resistance diagram with resistances as abscissas, taking values from the last two columns of the table.

Draw conclusions from the diagram in regard to

(1) the fall of potential in the resistances,

(2) the fall or rise of potential through the voltaic cells.

(3) What is represented by the slope of the lines of the diagram?

(4) What are the tests of accuracy?

TABLE.

One scale division of potential galv. = ...volts.
" " " ammeter = ...amp.

Current galv.		Parts of circuit.	Potential galv.			Resistance in Ohm's.	E.M.F. of cells.		Total from *a*.		
Reading. *	Amps.		Reading. *	Volts rise in potential.	Volts fall in potential.		Reading. * §	Volts.	To.	Volts.	Ohm's.
		a Cell No. 1 *b*							*b*		
		b R_1 *c*							*c*		
		c Cell No. 2 *d*							*d*		
		d R_2 *e*							*e*		
		e Cell No. 3 *f*							*f*		
		f R_3 *g*							*g*		
		g Cell No. 4 *h*							*h*		
		h R_4 *a*							*a*		
		Totals									

* Observed. § Circuit broken.

Experiment 99.

DETERMINATION OF THE E. M. F. OF A BATTERY.

Reference: Watson, § 480.

From Ohm's Law $$C = \frac{E}{R+R_0}$$

for a complete circuit, where C is the current flowing when E is the total effective *E.M.F.* and $R+R_0$ is the total resistance, R being the known resistance in the box and R_0 the unknown resistance.

Let C_1 be the current for a box resistance of R_1 and C_2 be the current corresponding to a known box resistance of R_2; then the expressions for the two currents will be

$$C_1 = \frac{E}{R_1 + R_0} \quad \text{and } C_2 = \frac{E}{R_2 + R_0}$$

If the I_0 of the galvanometer be known the current may be computed from the expression already obtained,

$$C = I_0 \tan \theta$$

Then as R_0 is the constant resistance outside the box in any case it may be eliminated between two equations and the value of E may be determined.

Put a galvanometer of 50 turns in series with a reversing key, a resistance box, and two gravity cells. (See Fig. 41.). Take four or more galvanometer readings, for direct and reverse currents, first making $R = 0$ then of such values as to reduce the galvanometer deflections to about ¾, ½ and ¼ the original deflections.

Compute values of C from the formula $C = I_0 \tan \theta$ and then by elimination, determine E.

Galvanometer No. $I_0 =$ Station No.

R	Galvanometer deflections			tan Θ	C
	Direct	Reverse	Av.		

Plot a curve using values of $\frac{1}{C}$ as y's and corresponding values of R as x's.

Experiment 100.

COMPARISON OF *E.M.F'S.* OF BATTERIES BY POTENTIOMETER METHOD.

Reference: Tory & Pitcher, Experiment 70, p. 232.

Apparatus. A sensitive galvanometer, a slide wire bridge and contact key, a resistance, cells to be compared, and cells to supply current.

Put a low resistance battery of *E.M.F.* greater than that of the cells to be tested in series with a wire of a slide wire bridge *ab*. At the point *a* connect the two cells to be compared so that their *E.M.F's.* will oppose the *E.M.F.* of the main battery. Connect them to the key *k* and complete the circuit

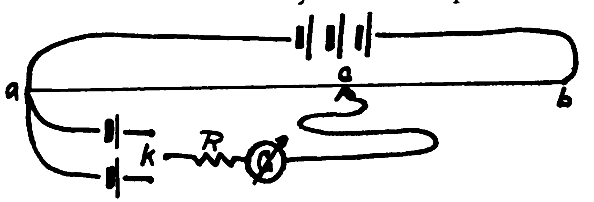


FIG. 47

through a variable resistance, a sensitive galvanometer and a flexible conductor to the sliding contact key at *c*.

If the fall of potential from *a* to *b* be greater than the *E.M.F.* of either of the cells to be compared some point, as *c*, may be found such that the fall from *a* to *c* is equal to the *E.M.F.* of one of the cells. If the key at *x* be closed, putting one of the cells in the lower circuit with the galvanometer then the slider *C* may be moved until some point is found, such that no deflection of the galvanometer is produced whether the lower circuit is closed or open. Then the plus terminal of the cell will be at the same potential as *a* and the minus terminal at the same potential as *C*, since no current is flowing; and the *pd* on the slide wire between *a* and *c* will be equal to the *E.M.F.* of the cell.

But $pd = Cr$ from Ohm's Law and $pd = E = Cr$ (1)

Treating the second cell in like manner some point of "balance" of the slider may be found such as C, so that no current flows through the galvanometer. Then $pd' = Cr' = E'$ (2)
But as no current flows in the lower circuit in either case and the resistance and *E.M.F.* of the main circuit are constant $C = C'$.

The slide wire is supposed to be of uniform cross section; therefore its resistance is proportional to its length and equation (1) may be written $E = Ckl$ (3) and equation (2) becomes $E' = C'kl'$ (4) Dividing (3) by (4) $\frac{E}{E'} = \frac{C\,l}{C'k\,l'} = \frac{l}{l'}$

That is, the *E.M.F.* of the cells compared are to each other as the lengths of wire about which they are shunted to produce zero deflection of the galvanometer.

Connect as shown in diagram putting the cells to be compared in the circuit between a and the key K. Close the key K putting one of them in the circuit and change the position of the slider to find zero deflection. Make the proper reading of the length ac. Then put the second cell in circuit cutting out the first and get a new balance, taking the proper reading ac'. Take alternate readings about the two cells until five readings have been made about the first cell and four about the second cell. Find the mean of each set. The ratio of these means will be the ratio of the *E.M.F.* As a check, read the *E.M.F's.* of each cell by means of a voltmeter.

Experiment 101.

ELECTROLYSIS.

ELECTROCHEMICAL EQUIVALENT OF COPPER.

References: Watson, §§ 539--540.

When an electric current passes through a salt solution, called an electrolyte, it is supposed that the salt is decomposed in a

manner explained in the text above referred to and one of the products of decomposition will carry positive electricity in one direction and the other product of decomposition will carry negative electricity in the opposite direction. These products of

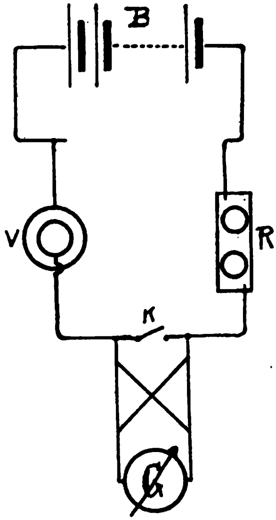


FIG. 48

decomposition are called ions, and these ions are thought of as carrying positive and negative charges. The quantity of electricity carried by a given mass of a substance is a perfectly definite amount and on this fact are based laws known as Faraday's Laws of Electrolysis. If the two terminals of an otherwise complete circuit be placed in a copper sulphate $CuSO_4$ solution it is found that electricity will flow in the circuit and that copper will be deposited on the terminal by means of which the current leaves the solution, called the kathode; and if the terminal by which the current enters the electrolytic cell, called the anode, be also of copper, some of this copper will go into solution. The mechanism by means of which this takes place may be looked on as follows. The $CuSO_4$ in solution breaks up into

Cu ions which carry + charges to the kathode and SO_4 ions which carry — charges to the anode. The Cu ions give up their charges at the kathode and are deposited on it as metallic copper. The SO_4 ions give up their — charges at the anode and combine with the copper anode to form $CuSO_4$ again, which in turn may be ionized. The amount of copper deposited is proportional to the quantity of electricity that has passed through the cell and to the electrochemical equivalent of the metal.

If m = mass of metal deposited, Q = quantity of electricity which has passed through the cell, and k is the electrochemical equivalent of the metal; then, $m = Q\,k = C\,t\,k$ since the quantity is equal to the product of the current into the time of flow of current.

The object of this experiment is to find the electro-chemical equivalent of copper in $CuSO_4$. Prepare two coils of copper winding them on the form supplied; the old wire on the larger cylinder and the new wire on the smaller cylinder. Remove the coils from the forms and fit them to the jar to contain the $CuSO_4$. Then wash the inner coil under a water tap, immerse it for 15 or 20 seconds in acidulated water, hold under tap again, roll on filter paper to get rid of as much water as possible, then rinse in alcohol and allow to dry, taking care not to handle the coil on parts which are to receive the deposit. Carefully weigh the small coil. Arrange the coils in the empty jar so that they will not touch and connect them in series with a galvanometer, a battery of constant *E.M.F.* and low internal resistance, and a regulating resistance frame. (An ordinary resistance box will not answer, as it will not stand so much current as is desirable).

Determine the direction of the current using a compass, and adjust the variable resistance to give a deflection of about 60° on the galvanometer, using a small number of turns. Place the cell in circuit so that the current may enter by the large coil. Pour in the $CuSO_4$ and close the circuit noting the time.

Make a run of an hour taking direct and reverse galvanometer readings every two minutes being careful not to break the circuit through the cell when reversing the galvanometer. This may be done by a short circuiting device, cutting out the galvanometer during reversals. When the run is finished remove the coils and wash them under a water tap, roll the gain coil on filter paper and then rinse in strong alcohol, after which the coil should be weighed as soon as it is dry.

From the I_0 and the mean deflection of the galvanometer C may be found; $C = I_0 \tan \theta$.

The time being observed and the mass of copper deposited being found k may be computed.

Great care must be used in this experiment as carelessness will most likely result in the necessity of making more runs.

Experiment 102.

MEASUREMENT OF THE CAPACITY OF A CONDENSER.

References: Watson, §§ 450–452, 460–463.

Nichols Lab. Manual, Vol. I, Experiment U_3.

If a condenser be put in a circuit with a battery and a ballistic galvanometer, and the circuit be closed, it will be found that the moving parts of the galvanometer will be momentarily deflected. The deflection will be caused by a momentary current flowing in the circuit which will supply enough electricity to charge the condenser. A current will flow for a very short time until the potential difference at the condenser terminals is equal to the *E.M.F.* of the battery.

The ballistic galvanometer is one used to measure quantity of electricity. Any galvanometer in which the damping is not too great may be used ballistically, but practical considerations make it advisable to use a galvanometer whose period is not so short as to make it hard to read the deflections, or so long as to use

up too much time. In accurate work allowance must be made for air and magnetic damping.

The quantity of electricity passing through the galvanometer in a time so short that the moving parts do not get appreciably away from their positions of rest before the whole electric charge has passed, may be expressed as follows : $Q = K\ (1 + \lambda/2)\ \delta$ (1) in which Q is the quantity of electricity that has passed through the galvanometer, K is the ballistic constant of the galvanome-

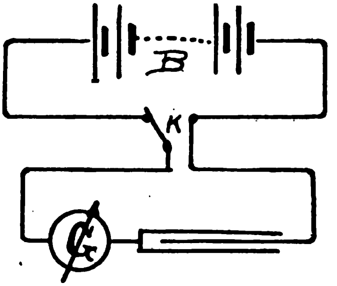


FIG. 49

ter, λ is its damping factor, (See Tory & Pitcher) and δ is the deflection for small deflections.

The capacity C of a condenser is that quantity of electricity that will produce unit difference of potential between its terminals. From this it follows that $Q = Cpd$ (2)

From equations (1) and (2) we get $Cpd = K\ (1 + \lambda/2)\delta$ (3)

and $C = \frac{K}{pd}\ (1 + \lambda/2)\delta$.

From the above expression it will be seen that if the ballistic constant of the galvanometer, its logarithmic decrement and the *E.M.F.* of the battery be known the capacity of a condenser may be determined. It will also be seen that the capacities of two condensers may be compared without knowing the galvanometer constant if the same *E.M.F.* be applied in each case,

since λ will be the same, for $C_1 = \frac{K}{pd}(1+\lambda/2)\delta_1$ and

$$C_2 = \frac{K}{pd}(1+\lambda/2)\delta_2 \text{ from which } \frac{C_1}{C_2} = \frac{\delta_1}{\delta_2}$$

The experiment consists in comparing the capacities of two or more condensers separately and also when in series and in multiple.

When condensers are connected in multiple

$$C_m = C_1 + C_2 + \ldots + C_n.$$

When the condensers are connected in series

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}.$$

Compare the computed and determined values of the capacities in series and in multiple.

Make connections as outlined below so that the condensers may be charged or discharged through the ballistic galvanometer. Make at least five observations of the throw of the galvanometer at charge and discharge for each arrangement of the condensers.

Arrange data as follows:

Galvanometer No. Capacity of Standard.

$K=$ Condenser= *mf.*

$\lambda=$

CONDENSER NO.

δ on charge.	δ on discharge	Average δ

Mean Averages δ

Capacity of condenser=

Experiment 103.

STUDY OF A MAGNETO MACHINE.

References: Watson, §§ 526–530.

S. P. Thompson, Electricity and Magnetism, §§ 461–465.

Nichols & Franklin, Vol. II, pp. 66–68.

The simple type of dynamo to be studied in this experiment is called a magneto because its field is produced by strong permanent magnets. The armature is a Gramme ring.

Let us consider one turn of the ring as it moves from its lowest point, where it comprises all the lines of force of the magnetic field which thread the lower portion of the soft iron core upon which the armature is wound, to its highest point where the lines of force of the magnetic field which thread the upper part of the ring pass through it. In traveling this distance the outer part of the turn cuts all the lines of force which thread the soft iron core, that pass from one pole of the field magnet to the other pole.

Let N be the number of lines of force running from the north pole of the field magnet to the south pole, n the number of revolutions of the armature per second, Z the total number of turns of wire on the armature, A the area of either pole face, and E the induced electromotive force.

The number of lines of force cut by one turn in one second when the turn is moving from its lowest to its highest position is Nn. The total number of lines of force cut by all the turns on the armature in one second when moving in a similar manner is therefore NnZ.

The number of lines cut per second when the turns are moving downward on the opposite side is also NnZ, but if brushes or leads to an external circuit are placed one above and one below, then the two sides act like two cells in multiple; that is, the generator has the $E.M.F.$ of either side acting alone, but

its internal resistance is decreased since there are two paths for the current. Therefore the induced *E.M.F.* due to conductors cutting across lines of force is $E = NZn$ since the induced *E.M.F.* is equal to the rate of cutting lines of force. This *E.M.F.* is in *c.g.s.* units. It may be reduced to practical units by dividing by 10^8. Therefore $E = \frac{NZn}{10^8}$ volts.

From the above equation it may be seen that the *E.M.F.* varies with the speed if the field strength and the number of conductors remain constant. If the generator is an open cir-

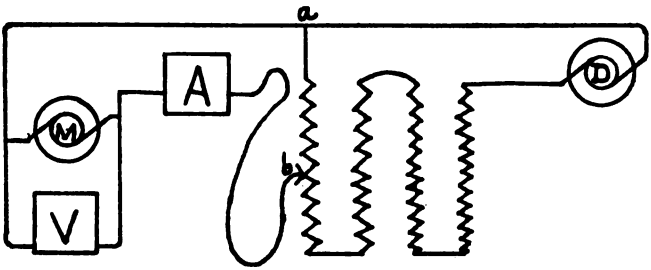


FIG. 50

cuit the *pd.* between its terminals is equal to its *E.M.F.* since no current flows. (See Exp. 100.)

If a high resistance voltmeter be connected to the brushes of the machine it will indicate voltage within a small percentage of error since the current allowed to flow will be very small and consequently the loss of energy within the generator may be neglected.

I.

Connect a voltmeter having a 15 volt scale, or of that range, to the brushes of the machine. Run the dynamo at such a speed as to keep the voltmeter reading as nearly constant as possible for one minute. Get the speed of the machine with a speed counter and observe the voltmeter reading often enough to get a good average reading. Make observations for six or eight different voltages distributed well over the scale. Sir

the magnetic field is constant the voltage varies with the speed. Plot a curve using *r.p.s.* as abscissas and corresponding voltmeter readings as ordinates. Draw the best line possible to fit the points. The line must go through the origin. Why?

Measure the area of one pole face and compute the average number of lines per sq. cm.

II.

Connect an adjustable tin resistance frame in series with an ammeter and the brushes of a dynamo. Connect the voltmeter across the brushes. Run the dynamo at a moderate speed, read the ammeter and voltmeter and take the speed of the dynamo for various resistances in the frame. Make at least five observations.

Plot a curve using voltmeter readings as ordinates and external resistances as abscissas. Find the current flowing for each set of readings.

From the first curve find the E of the dynamo for the speeds used. The difference between the E's and voltmeter readings for the same speeds in cases I and II will give the loss of voltage within the dynamo. This loss is equal to the current flowing times the resistance of the generator.

Then $E—pd = Cr$ from which it is seen that the resistance of the generator is the only unknown. Solve for r for each set of observations.

The values of r computed should all be alike.

Resistance in frame.	Voltmeter readings.	Ammeter readings.	Revolutions in one minute.	*r.p.s.*	E	$E—pd.$	$r.$

As a check the resistance of the armature may be determined by keeping it from rotating, sending a known current through it, measuring the potential difference at its terminals, and applying Ohm's law $pd = Cr$.

III.

To use the dynamo as a motor. Put a large resistance frame in series with a dynamo. Leads shunted off at different points on the frame will make it possible to apply different values of *pd* to run the dynamo as a motor. Put the ammeter in one of these leads in series with the motor. Shunt the voltmeter across the motor brushes. The following diagram outlines the connections.

When the machine is running as a motor, according to Lenz' law it develops a counter electromotive-force: that is, an *E.M.F.* which opposes that which produces it. The *pd* at the motor terminals must be sufficient to balance the counter *E.M.F.* and also the loss of potential within the machine due to current flowing through the resistance of the machine. From this it follows that $pd = e + Cr$.

Make a series of voltmeter and ammeter readings for different speeds of the motor from very low speeds to such speeds that the limits of the measuring instruments are reached. This may be done by shifting the contact point *b* along the tin resistance. Before making a reading wait until a steady speed is reached, then read the instruments and take the speed. Knowing the resistance of the motor the potential loss *Cr* may be computed.

From the first curve the counter *E.M.F.* *e* may be obtained.

Compute the counter *E.M.F.* from the expression $e = pd - Cr$ and compare this with the value obtained from the first curve.

Resistance of armature =

Ammeter reading.	Voltmeter reading.	r.p.s.	*Cr.*	*pd—cr.*	*e* from the curve in case 1.

Draw a curve using values of *pd—cr* as abscissas and corresponding values of *r.p.s.* as ordinates.

PART VI.

TABLES.

I. SOME USEFUL TABLES IN WATSON'S PHYSICS.

2. SOME USEFUL NUMBERS.

$\pi = 3.1416$	$2\pi = 6.283$	$4\pi = 12.57$
$\pi^2 = 9.87$	$4\pi^2 = 39.48$	$1/\pi = 0.318$
$\frac{1}{2}\pi = 0.159$	$\pi/4 = 0.0796$	$\log.\ \pi = 0.4971$

1 Radian $= 57^\circ.3$

$1^\circ = 0.01745$ radians

Approximate value of $g = 980$. $\sqrt{980} = 14\sqrt{5} = 31.3+$

$1/\sqrt{980} = 0.032$

Work and Power.

1 Joule $= 10^7$ crgs.

1 Watt $= 1$ Joule per second.

1 Horse Power $= 746$ Watts.

Mechanical equivalent of heat $= 4.18 \times 10^7$ ergs.

Velocity of sound at 0° C. in dry air $= 331$ m/sec.

Velocity of light $= 300000000$ m/sec.

Electrochemical equivalent of copper $= 0.000328$.

3. Density of Some Substances.

Solids.			
Aluminum,	2.7	Lead,	11.3
Beeswax,	0.96	Paraffin,	0.87—0.93
Brass,	8.1—8.7	Silver,	10.5
Copper,	8.5—8.9	Tin,	7.3
Cork,	.14— .3		
Glass Common,	2.4—2.7		
" Flint,	3.0—5.9	Woods seasoned,	
Hard Rubber,	1.15	Oak,	0.7—1.0
Iron: Cast,	7.1—7.7	Pine,	0.5
" Wrought,	7.8		
" Steel,	7.8	Zinc,	7.1

Liquids at 20 °C.			
Alcohol,	0.789	Glycerin,	1.23
Carbon Bisulphide,	1.264	Mercury,	13.546
Copper Sulphate, 10%	1.1	Zinc Sulphate 10%,	1.1

4. Elastic Constants.

Substances.	Young's Modulus. dynes per sq. cm.	Simple Rigidity. dynes per sq. cm.
Aluminum,	6.5×10^{11}	$2.4—3.3 \times 10^{11}$
Brass,	8.3—9.7	3.1—3.6
Copper,	9.8—12.0	4.5
Glass,	6.0— 7.0	2.4
Iron: Wrought,	19.3—20.9	7.7—8.0
Steel,	19.0—22.0	8.0—8.8
Woods: Oak,	1.0	0.07
Pine.	1.1	0.10

5. HEAT CONSTANTS OF SOLIDS.

Substance.	Coefficient of Linear Expansion.	Specific Heat.
Aluminum,	0.000023	0.212
Brass,	0.000019	0.094
Copper,	0.000017	0.094
Glass,	0.000008	0.188
Lead,	0.000028	0.032
Iron,	0.000012	0.112
Zinc.	0.000029	0.094

6. INDEX OF REFRACTION FOR SODIUM LIGHT.

Alcohol,	1.362
Canada Balsam,	1.54
Carbon Bisulphide,	1.628
Glass; Crown,	1.515—1.615
Flint,	1.609—1.752
Water,	1.333
Calcite; Ordinary ray,	1.659
Extraordinary "	1.486
Quartz; Ordinary "	1.544
Extraordinary "	1.553

7. ELECTROMOTIVE FORCE OF CELLS.

Edison Lalande	0.7,	LaClauche	1.4—1.7
Daniell	1.08,	Bichromate	2.0
Gravity	1.1,	Storage	2.0
Dry Cell,	1.4,		

E.M.F. Standard Cells at 20°C.

Clark	1.427	Weston (Cadmium)	1.019

8. Wire Gauge and Copper Resistance Table.

Size B and S.	Diameter in inches.	Ohms per 1000 ft.	Feet per ohm.
0	.32495	.0983	10166
4	.20431	.2487	4021
8	.12849	.6288	1590
10	.10189	1.0000	1000
12	.08081	1.590	629
14	.06408	2.528	396
16	.05082	4.019	248.8
18	.04030	6.391	156.5
20	.03196	10.163	98.4
24	.02010	25.695	38.92
28	.01264	64.97	15.39
32	.00795	164.3	6.09
36	.00500	415.2	2.41
40	.00314	1049.7	.953

ıBLE.

ɔer ohm.

6
I
o
ɔ
)
ı
ı.8
·5
·4
.92
39
09
41
953